EVALUATION OF CO_2 MANAGEMENT MEASURES

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Executive Summary

Scientists have long been concerned that changes in the chemical composition of the earth's atmosphere could result in significant variations in global climate. Although considerable debate about the extent and timing of possible changes continue, efforts are underway to develop policies to meet the challenges of global warming.

Much of the recent policy discussion has focused on abatement of carbon dioxide emissions. Following work by a federal/provincial Task Force on Energy and the Environment and a provincial inventory of carbon dioxide emissions, the Province of British Columbia is undertaking a four-part Greenhouse Gases Project. The ultimate goal of the project is to develop a comprehensive strategy for greenhouse gas management for the Province. The four parts of the project are:

- Inventory and Management Measures for NO_x/VOC/O_3;
- Inventory and Management Measures for CFC's and Related Gases;
- Inventory and Management Measures for Methane; and
- Evaluation of Carbon Dioxide Management Measures.

This report documents the results of the evaluation of carbon dioxide (CO_2) management measures.

I. Objectives and Scope of the Study

The objective of the study was to develop a list of potential measures and technologies that could reduce net CO_2 emissions and to evaluate those measures with respect to overall ease of implementation. The criteria used for evaluation were:

- CO_2 abatement potential;
- cost-effectiveness (defined as the cost of eliminating one tonne of CO_2); and
- attitudinal, institutional, or other non-monetary barriers to implementation.

First, a long list of measures for each sector was screened based on abatement potential and cost-effectiveness. In the final assessment, which incorporated barriers to implementation, measures were allocated to one of five categories:

I. Measures that are economic with low barriers to implementation.

II. Measures that are economic with high barriers to implementation.

III. Measures that incur moderate costs and have low barriers to implementation.

IV. Measures that incur moderate costs and have high barriers to implementation.

V. Measures that may emerge from new, as yet unproven technology.

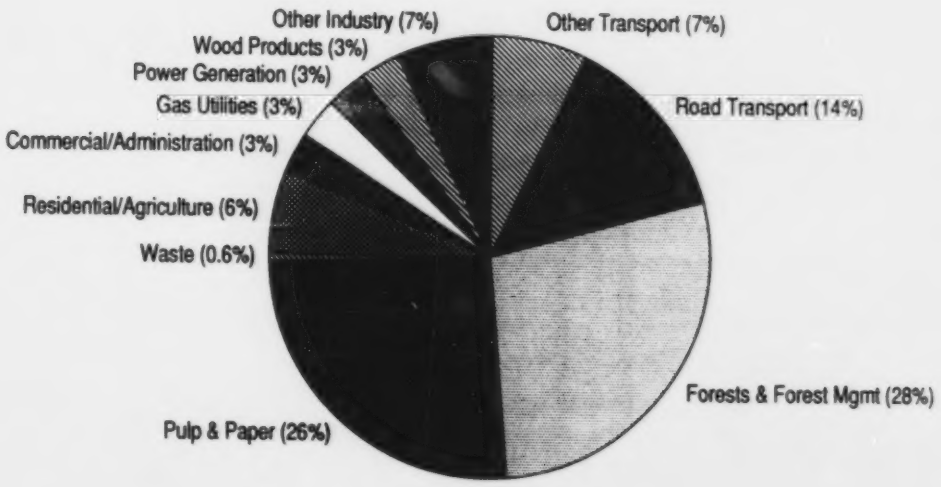
This study focuses on measures that are commercially economic; that is, measures that are economic from the perspective of the user. Differing discount rates, taxes and other price distortions can cause private and social assessments to diverge. Where these factors are important, they have been noted.

An overview of possible policy tools was also developed as a first step in developing a CO_2 strategy. However, the study stopped short of developing that strategy; that task falls to the Greenhouse Gases Project Team within the provincial government who will coordinate the requirements and priorities of managing all greenhouse gases.

Sources of Carbon Dioxide Emissions in B.C.

The profile of CO_2 emissions used as a base for this study is summarized in the pie chart below. As indicated, emission sources are dominated by:

- Forests and Forest Management (prescribed burning, wood residue and forest fires);
- Pulp and Paper;
- Road Transport; and
- Residential/Agricultural.



Sources of Carbon Dioxide Emissions in B.C.

(Total 1989 emissions = 93 million tonnes)

These four sectors, which account for almost 75% of total provincial emissions are the focus of this study. In addition, power generation and the role of forests as a sink are addressed.

II. Management Measures

A total of 45 individual measures were identified and assessed on the basis of abatement potential and cost-effectiveness. The majority of transportation measures were found to be cost-effective and generated moderate emission reductions. Forest and forest management measures, by contrast, had much greater abatement potential but none offered cost savings. Residential measures varied considerably with respect to cost-effectiveness and abatement potential, with differences even within a measure depending on its application (e.g., single family or multiple unit dwelling).

Measures with moderate to high abatement potential and moderate to high cost-effectiveness are listed in Exhibit ES.1.[1] These are considered to be promising measures. As indicated in the exhibit, measures from all sectors are included, although residential measures are relatively under-represented. Only two measures have high abatement potential *and* are likely to yield cost savings: vehicle fuel efficiency measures in the road transportation sector and general energy efficiency measures in pulp and paper. Measures for each sector are summarized below.

Forests and Forest Management

Planting "Not Sufficiently Restocked" (NSR) forest lands and marginal agricultural land in B.C. could increase CO_2 absorption by 4150 - 5310 kt per year or about 5% of provincial emissions. Collectively, these two measures represent one of the most promising measures from the perspective of abatement.[2] However, the measures are costly: $1-3 per tonne CO_2 removed or more than $650 million in total.

The incremental CO_2 absorption offered by planting NSR and marginal agricultural lands is a temporary measure. Once the lands are planted, they enter a harvest-regeneration cycle so that the CO_2 accumulation estimates noted above are valid for one rotation only (about 80 years). Nonetheless, this stop-gap measure could provide a valuable window during which new technologies or new patterns of consumer behaviour can be developed to address CO_2 emissions on a ongoing basis.

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[1] Definitions of moderate and high are:

	High	Moderate
Abatement potential (% of 1989 provincial emissions)	> 2%	0.5 - 2%
Cost-Effectiveness ($ per tonne CO_2 abated)	< $0	$0 - $10

[2] Measures to enhance forest productivity and to reduce energy consumption generated relatively small increments to CO_2 absorption.

Exhibit ES.1: Promising CO_2 Management Measures

Measure	Annual Abatement Potential (kt)	Cost-effectiveness ($/tonne)	Barriers to Implementation	Category*
Forests & Forest Management				
Utilization of harvest residues & wastes	2210+	M	H	IV
Plant NSR lands	2360-3020	M	L-M	III
Plant marginal agricultural land	1790-2290	M	M	III
Pulp and Paper				
General efficiency measures	4400	H	L	I
Process changes	1945	M	H	IV
Substitution to natural gas	445	H	L	I
Substitute to 100% self-generated fuels	3805	M	M-H	IV
Transportation				
Driver training	515	H	L-M	I
Route & traffic planning	765	H	M	I
Vehicle maintenance	540	H	L	I
Conversion to natural gas	955	H	M	I
Conversion to propane	895	H	M-H	II
Public transportation	485	H	M-H	II
Trip reduction measures	580	H	M-H	II
Vehicle fuel efficiency	2010	H	M	II
Residential				
User education / practices	530	H	L	I
Passive solar (space heating)	1415	H	M	II

Source: Exhibit 9.1 and ARA Consulting Group

***Definitions:**

Timeframe:
- S: Short-term — within 5 years
- M: Medium-term — 5-10 years
- L: Long-term — after 5 years

Note: Refers to time at which measures begin to affect carbon dioxide emissions / fixation.

Abatement Potential:
- L: Low — <0.5% of 1989 provincial emissions
- M: Moderate — 0.5% to 2% of 1989 provincial emissions
- H: High — >2% of 1989 provincial emissions

Cost-effectiveness:
- L: Low — >$10 / tonne CO_2
- M: Moderate — 0-$10 / tonne CO_2
- H: High — <$0 / tonne CO_2

Barriers:
- L: Low
- M: Moderate
- H: High

Category:
- I Measures that are *cost-effective* (i.e. generate savings) with *low barriers* to implentation
- II Measures that are *cost-effective* with *high barriers* to implementation
- III Measures that have *marginal costs* with *low barriers* to implementation
- IV Measures that have *marginal costs* with *high barriers* to implementation

Planting NSR and marginal agricultural lands are not without their difficulties and risks. At a fairly basic level, much is still unknown about the carbon balance of temperate forests and B.C. forests specifically. Research is underway in the B.C. Ministry of Forests and Forestry Canada, but many uncertainties linger. The figures for CO_2 absorption above are based on preliminary estimates of carbon uptake and other variables and, therefore, are subject to confirmation. In addition, there is concern that global warming itself may compromise growth and survival rates and, consequently, CO_2 absorption capability.

Incineration of harvest residues and wood residues represents a major source of emissions in the province. Although no conclusions were drawn regarding the role of slash burning in CO_2 management (because site-specific factors preclude generalizations), diversion of harvest residues and wood wastes (from wood products and pulp and paper operations) to alternative, durable end products or energy resource could significantly reduce emissions. For example, a 10% diversion of wastes annually could reduce provincial CO_2 emissions by some 2 million tonnes per year or 2.3%. Increased utilization of wastes does, however, face considerable technological and market challenges. Although various reports suggest product opportunities exist, industry representatives seriously question these conclusions, citing high risks associated with new product introduction and cost factors.

The role of forests as a store of carbon underscores the importance of judicious harvesting and attentive regeneration. Corollary measures include increased use of fibre in durable products to "lock in" carbon over the long term and improved efficiency of fibre use, although neither abatement potential nor cost-effectiveness could be quantified in this study.

Intensive forest management practices and urban tree planting were not included in the list of promising measures because they are not expected to significantly reduce emissions.

Pulp and Paper

The pulp and paper sector is the single largest energy user in the Province and, based on that energy profile, is one of the main sources of CO_2 emissions. Since the first oil crisis, the industry has made better use of waste products, such as wood residues and pulping liquor, as replacement fuels for oil and natural gas. This has helped reduce CO_2 emissions. Further opportunities for substitution exist, both in terms of continued substitution of oil by natural gas or of oil and natural gas by self-generated fuels. As indicated in Exhibit ES.1, substitution to 100% self-generated fuels could reduce emissions by almost 4 million tonnes per year, or 4% of the provincial total.

Also, it seems reasonable to conclude that a continuation of the general efficiency measures of the past two decades is possible, although the rate of implementation will depend on energy prices and other priorities of the industry. Such a trend could reduce emissions by some 4400 kt per year (4.7% of provincial emissions) while generating cost savings.

Although barriers to these measures have been characterized as low, they do exist. Specifically, the current poor financial health of the industry has tightened cash constraints and compromised

the ability and advisability of raising funds to undertake energy conservation projects, even though they may be economically sound in the long term. Second, many industry representatives accord a relatively low priority to the CO_2 issue, partly because of the urgency of other environmental matters, such as compliance with new federal and provincial effluent regulations.

Process changes include diversion from kraft to recycle or mechanical pulping techniques. Recycle and mechanical pulping offer opportunities for significant reductions in CO_2 emissions because:

- they are considerably less energy-intensive; and
- they generate less wood residues and pulping liquors that must be disposed of.

However, process changes generally require considerable investments that can approach levels required for greenfield mills. Process changes also, by definition, change the final product; hence, the decision to move to mechanical or recycle pulp is complex and must take into account an array of market factors and risks. In the case of recycle pulp, the potential for substitution from kraft production is limited by the availability of raw material -- in this case, post-consumer paper. While some potential for recycled pulp exists in B.C., the transportation economics of bringing post-consumer paper to B.C. for processing do not lie in the Province's favour. For these and non-CO_2 environmental reasons, barriers to process changes are considered to be high.

Transportation

The road transportation sector is one of the largest oil-consuming sectors in the Canadian economy. Considerable research, particularly in California, has focused on "weaning North Americans from their love affair with the automobile", and has resulted in a fairly rich body of energy conservation opportunities. Promising measures in the road transportation sector include vehicle efficiency, traffic management, trip reduction and interfuel substitution measures.

Although some believe that the internal combustion engine is facing inherent performance limits, much of the literature suggests that further improvements in fuel efficiency are possible from weight reductions, improvements to aerodynamics, and engine and drive train modifications. The measure examined in this study -- a 17% improvement in average fleet efficiency -- generates significant emission reductions and cost savings. The primary barriers associated with vehicle efficiency improvements are consumer preferences (driven in part by oil prices) and the ability of a single jurisdiction such as B.C. to influence global vehicle design decisions.

Energy conservation and emission control through trip reduction measures have received considerable attention in California (Regulation XV) and other U.S. municipalities. The City of Vancouver is also considering such measures as part of their air quality program. The basic tenent behind trip reduction measures is to change incentives that affect transportation mode choices by employees. In general, several individual measures, such as parking policies, ridesharing programs and promotion of public transportation are combined into a trip reduction plan.

By increasing average vehicle ridership (AVR), California's Regulation XV expects to reduce daily trips by 750,000 and vehicle miles per day by some 15 million. The measure examined in this study -- parking and rideshare measures to increase AVR from 1.3 to 1.5 people -- could reduce emissions by about 600 kt per year (less than 1% of provincial emissions). Like public transportation, trip reduction measures require changes in lifestyles that may compromise flexibility, independence and convenience. Consequently, moderate to high barriers could impede implementation of trip reduction and similar measures.

Conversion of vehicles to alternative transportation fuels could yield abatement benefits. Based on "best guess estimates" on a life cycle basis, propane and CNG (compressed natural gas) could reduce CO_2 emissions by about 1% of provincial emissions. With today's retail price structure, conversion to either fuel would provide cost savings, although the attractiveness of conversion to natural gas is partly driven by its exemption from the provincial road tax. The main barrier to conversions is the technical uncertainty surrounding CO_2, VOC and other emission performance of alternative fuels. Other barriers include performance, availability of fuel, and safety and environmental considerations.

Ethanol and hydrogen fuels may offer more significant abatement opportunities in the future but the technology is as yet unproven. Electric vehicles, which have received considerable attention in California's clean air strategies, also show promise but infrastructure and battery problems hamper commercial introduction. Californian regulations that set a target for "zero-emission vehicles" of 2% of annual car sales by 1998 will maintain pressure to solve these problems.

Residential Sector

Only two residential measures are included in the list of promising measures: user education/practices and passive solar for space heating. User education/practices encompasses a package of behavioral adjustments, such as lowering thermostat settings and housekeeping items to prevent heat loss. The main concern with implementation of this measure is to find the most appropriate and effective vehicle for public education.

Emission reductions from more extensive application of passive solar could generate emission abatement of about 1400 kt per year, or 1.5% of provincial emissions, arising primarily from substitution of natural gas. Barriers to implementing this measure are financial, institutional and attitudinal. For example, consumers are not generally well informed about the potential benefits of passive solar nor about available technologies. Furthermore, solar practices require home/building owners to make up-front capital investments on their own account, capital costs that must be borne at the individual's cost of capital rather than included in (oil, natural gas or electricity) fuel payments and spread out over many years.

The attractiveness of other residential energy conservation measures, such as direct solar for water heating and building envelope retrofits, vary considerably among applications, but generally do not yield a sufficiently potent combination of abatement potential and cost-effectiveness to include them on the list of promising measures.

The most effective management measures in terms of reducing CO_2 emission in the residential sector are also the most expensive. Conversion of LFO and natural gas to electricity could reduce emissions by more than 3850 kt per year (4% of provincial emissions) assuming today's mix of power sources. However, the cost of such conversions would exceed $20 per tonne CO_2 reduced.

Power Generation

Hydroelectric power represents a significant resource that reduces B.C.'s CO_2 emissions well below those in jurisdictions that rely on coal, oil and natural gas. The dominance of hydro does, however, limit opportunities for further reducing CO_2 emissions from the electrical generating sector. Some reduction could be garnered by eliminating the use of the Burrard thermal plant, but this option could hamper the utility's capability to satisfy peak demand. Alternative energy sources (e.g., wind) are still considered a long-term proposition.

Some of the CO_2 management measures discussed in other sectors focus on converting from oil, natural gas, etc. to electricity and raise the question as to B.C. Hydro's likely response to meet an increase in demand. At the two extremes are a CO_2-intensive response and a hydro-intensive response. A CO_2-intensive response would meet demand by:

- increasing purchases from Alberta;
- reducing exports to the United States and Alberta; and
- using the full capacity of the Burrard thermal plant.

The sources could meet demand increases up to about 15% of projected loads, resulting in an emission factor for electricity of about 60 t/TJ compared to the current system average of 12 t/TJ.

The hydro-intensive response would use hydro potential to its maximum and would result in an emission factor for incremental electricity supply of less than 4 t/TJ (for 10% increase in demand). The pace of demand increases is, however, central to the viability of the hydro-intensive option. Should demand increase rapidly (e.g., 20% by 1995/6), sufficient hydro resources could not be made available and some CO_2-intensive options would be required.

Resource management decisions by B.C. Hydro can, therefore, affect CO_2 abatement potential of conversions to electricity and, conversely, measures that promote conservation of electricity. The estimates of CO_2 abatement from fuel switching that are presented in the main body of this report assume a supply response that favours hydro, but does not reflect the maximum reductions possible if a hydro-intensive strategy were followed. Relative to these estimates, a CO_2-intensive supply response would increase the attractiveness of electricity conservation measures and decrease the attractiveness of conversions. Results of a sensitivity test using an electricity emission factor of 60 t/TJ indicates that conversions of natural gas and LFO to electricity in the residential sector could still generate emission reductions, but at minimal levels and with a further increase in the cost per tonne CO_2 abated.

Social Cost Considerations

As noted above, this study focuses on the attractiveness of individual measures from a commercial or private perspective; that is, the "economics" from the perspective of the individual/company implementing the measure. However, the costs of a measure can differ when viewed from the perspective of society as a whole for two main reasons:

- costs are discounted as different rates reflecting different costs of capital; and
- taxes and price regulation create a divergence between retail and social (resource cost) energy prices.

Two sets of sensitivity analyses were run to examine the implications of a social cost perspective. The only substantive changes suggested by a social cost approach was to eliminate public transportation and conversion of private road vehicles to natural gas from the list of promising measures.[3]

III. Policy Tools

Policy instruments -- the tools by which management measures can be implemented and promoted -- can be grouped into seven categories:

- Research, Development and Demonstration (RD&D)
- Information
- Regulations
- Financial incentives
- Taxes and fees
- Marketable permits
- Direct government action.

The relevance of each of these types of instruments to the management measures identified above is presented Exhibit ES.2. As indicated, RD&D, public education, and various financial instruments can be applied to most of the management measures. However, the appropriateness of any specific application should be assessed with respect to flexibility, ability to monitor effectiveness, information needs and administrative requirements, and distributional and equity considerations. Potential complementarities, synergies and conflicts among policy tools considered for different measures should also be evaluated.

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[3] Current tax structures favour natural gas and propane fuels over gasoline and diesel; when taxes are netted out, energy savings do not cover costs of conversion for natural gas conversions of private vehicles. Conversion of commercial vehicles remains cost-effective, partly because capital costs are spread out over greater energy use and, therefore, energy savings.

Exhibit ES.2: Policy Instruments to Implement Promising CO_2 Management Measures

	RD &D	Information			Regulations		Financial Incentives			Taxes and Fees			Market-able Permits	Direct Gov't Action	
		Labels / Rating	Audits	Public Education	Perform-ance Standards	Building Codes	Tax Incentive	Low Cost Loans	Direct Payments	Energy Tax	Carbon Tax	Other Tax		Planning	Investment
Forests & Forest Management															
Utilization of harvest residues & wastes	✔						✔				✔		?	✔	
Plant NSR lands	✔			✔			✔		✔				?		✔
Plant marg. agricultural lands	✔			✔			✔		✔				?		✔
Site treatment	✔										✔		?	✔	
Pulp & Paper															
General efficiency measures	✔	✔	✔	✔	✔		✔			✔	✔		✔		
Process changes	✔						✔	✔		✔	✔		✔		
Substitute to 100% self-generated fuels	✔						✔	✔		✔	✔		✔	✔	✔
Substitution to natural gas							✔	✔			✔		✔		
Transportation															
Vehicle fuel efficiency	✔	✔			✔					✔	✔	✔	✔	✔	
Driver training				✔			✔		✔	✔	✔		✔		
Route & traffic planning	✔			✔						✔	✔		✔		✔
Vehicle maintenance					✔					✔	✔		✔		✔
Conversion to natural gas	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Conversion to propane	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Public transportation				4			✔			✔	✔	✔	✔		✔
Land use planning					✔	✔	✔					✔		✔	
Residential															
User education / practices			✔	✔			✔			✔	✔		✔		
Passive solar	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔		✔		✔

IV. Conclusions: CO_2 Management Opportunities

This study has identified a number of management measures that can reduce CO_2 emissions while generating energy cost savings. These measures are not additive because some preclude others (e.g., conversion from gasoline to propane precludes the benefits of conversion to natural gas) and potential CO_2 reductions are dependent on the sequence in which measures are introduced. However, the maximum abatement potential of measures that are cost-effective *and* have low barriers to implementation (Category I measures) is *generously and roughly* estimated at about 8 million tonnes CO_2 per year, or less than 10% of current emissions.[4] These emission reductions stem almost entirely from transportation (3 million tonnes per year) and pulp and paper (5 million tonnes per year) measures. A negligible amount is contributed by user education in the residential sector.

The two most important and cost-effective measures are:

- general energy efficiency improvements in the pulp and paper industry (over 4 million tonnes per year, based on a continuation of energy use trends in the industry over the last two decades); and

- vehicle fuel efficiency improvements (about 1.5 million tonnes per year), although B.C.'s ability to influence car design is limited.

The full complement of cost-effective measures (i.e., Categories I and II, including those that face high barriers to implementation) are again dominated by transportation and pulp and paper measures, accounting for about 45% and 40% of maximum abatement potential, respectively. Residential measures contribute an additional 15%, most of which is generated by passive solar applications with significant barriers to implementation.

If the most promising re/afforestation programs are considered (Category III measures), maximum abatement potential could rise to about 17 million tonnes per year, or about 18% of current provincial emissions. Although these measures are costly ($650 to $750 million or $1-3 per tonne CO_2) and questions regarding the overall long-term balance of harvesting and forest regrowth remain, these planting measures could afford important "breathing space" during which time research, technological development and public education could generate long-term solutions to the CO_2 problem.

Additional abatement is feasible from Category IV measures such as process changes in the pulp and paper industry; however, the uncertain economics of these measures combined with their high barriers to implementation suggest that abatement from these measures would fall short of the maximum potential estimated in this study.

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[4] This figure overstates the abatement potential of Category I measures in that it takes into account only gross overlapping of measures. The cumulative effects of sequenced introduction of measures have not been taken into account.

Maximum potential emission reductions from different combinations of measures are suggested in the table below. We emphasize that these figures are in every sense maximum potential; they overstate realizable potential because only gross overlapping of measures has been taken into account. The cumulative effects of sequenced introduction of measures have not been incorporated.

	Max. Abatement Potential of Different Measures (kt per year)		
Sector	**Category I**	**Categories I-III**	**Categories I-IV**
Forests	-	4,100-5,300	6,400-7,500
Pulp and paper	4,800	4,800	10,100
Road transportation	2,700	5,900	5,800
Residential	500	1,500	2,000
Total	**8,000**	**16,400-17,600**	**24,300-25,400**
(% prov. emissions)	(9%)	(18%)	(27%)

In summary, B.C.'s abundance of hydroelectric power and natural gas offer opportunities for CO_2 management, but are not the panacea that they may appear to be at first glance. Although abundant, hydroelectric power is expensive from both cost and environmental perspectives; and the use of natural gas in the oil-dominated transportation sector faces the same barriers and problems as in other jurisdictions. In fact, considerable switching from oil to natural gas that has occurred in B.C. in the past 20 years limits the extent of additional CO_2 abatement opportunities in the residential sector.

Based on the analysis in this study, a CO_2 management strategy for British Columbia will focus on the transportation and pulp and paper sectors. An aggressive strategy aimed at reducing emissions by more than 15% will require costly measures such as planting NSR and marginal agricultural land.

1.0 Introduction

Scientists have long been concerned that changes in the chemical composition of the earth's atmosphere could result in significant variations in global climate. Although considerable debate remains, current discussions focus on policies to meet the challenges of global warming.

Much of the policy discussion has addressed carbon dioxide. An international conference in 1988 in Toronto on "The Changing Atmosphere: Implications for Global Security" recommended a global reduction in carbon dioxide emissions of 20% of 1988 levels by the year 2005. In response, Canadian federal, provincial and territorial ministers formed the Task Force on Energy and the Environment. The Task Force's *Report on Reducing Greenhouse Gas Emissions* provided the basis for actions and CO_2 management, yet further work was needed.

The Province of British Columbia is responding to the global warming issue under the Greenhouse Gases Project. An initial inventory and forecast of CO_2 emissions completed in 1990 took a critical step towards understanding the sources and sinks in the Province of one of the most important of the gases. Subsequently, the Province initiated four additional studies to provide background information to support a comprehensive global warming management strategy for the Province. The four studies are:

- Inventory and Management Measures for NO_x/VOC/O_3;
- Inventory and Management Measures for CFC's and Related Gases;
- Inventory and Management Measures for Methane;
- Evaluation of CO_2 Management Measures.

This project addresses CO_2 management measures.

Objectives of the Study

The objectives of the study are to develop a list of potential measures and technologies that can reduce net CO_2 emissions and to evaluate those measures with respect to technical abatement potential, cost-effectiveness, and non-economic or institutional considerations. The results of the assessment is then used as a basis on which to categorize measures according to overall ease of adoption.

This study focuses on identifying measures that are commercially economic, that is, measures that are economic from the perspective of the user. Differing discount rates, taxes and other price distortions can cause private and social assessments to diverge. Where these factors are important, they are noted.

The true impacts of measures will depend on the specifics of each application. Because the estimates presented in this report have been based on energy saving and other values developed in other jurisdictions, they are only indicative of abatement potential and cost-effectiveness, rather than definitive.

Structure of the Study

The study, by The ARA Consulting Group Inc. in association with H.A. Simons Ltd. and IBI Group Inc., was conducted in three phases. The first phase included initial assessment of a long list of possible measures. Based on preliminary cost-effectiveness and abatement estimates, a number of promising measures were identified and examined in more detail, including an assessment of the institutional barriers to adoption. The resulting Phase II categorization of measures satisfies the primary objectives of the study.

In Phase III, potential policy tools were discussed both in general terms and with respect to specific management measures. The study *did not* attempt to develop a CO_2 abatement strategy. Such an exercise lay outside the scope of this study. The purpose of Phase III was simply to indicate possible policy tools and to provide the framework for policy analysis.

The CO_2 study focuses on the main sources and sink of carbon dioxide in the Province:

- Forests and Forest Management
- Pulp and Paper
- Road Transportation
- Residential
- Electricity Generation.

Together, these sources account for 75% of total provincial CO_2 emissions (1989) and the major sink: forests.[1]

Organization of the Report

The report begins with a discussion of the general methodology and definitions used in the study. This discussion is supplemented with detailed working tables for abatement and cost-effectiveness calculations (Appendix A).

Chapters 3 through 8 present the results of the analysis and concepts behind management measures for each of the five main sectors plus CO_2 extraction and geoengineering. The focus in these chapters is on:

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[1] The ocean represents a second major sink for carbon dioxide. Some measures to enhance carbon uptake in oceans are identified in Chapter 8 on CO_2 extraction and geoengineering, but an in-depth investigation is beyond the scope of this study.

- identification of a long list of potential management measures;
- estimates of potential for reducing CO_2 emissions/increasing absorption of CO_2; and
- cost-effectiveness of the measures.

Chapters 3 through 8 are not comprehensive and the reader is cautioned that the analyses presented in those chapters serve as a screen to identify promising measures for further evaluation.

Chapter 9 presents a synthesis of the preceding chapters, suggests a list of approximately 17 promising measures, and examines institutional barriers to adoption. Chapter 9 concludes with the categorization of measures according to ease of implementation.

Chapter 10 discusses policy tools, and the most important conclusions of the study are presented in Chapter 11. A glossary and bibliography follow Chapter 11.

The appendices to the report contain working tables, emission factors, energy and emission forecasts, sensitivity tests, and a list of contacts.

2.0 Methodology

In this section, we outline the methodology used to develop the abatement and cost-effectiveness values presented in Sections 3 through 6 and to categorize measures in Section 9. The section begins with a discussion of the emission profile used as a base for the analysis and the information sources. Specifics of the calculations of abatement potential and cost-effectiveness follow. The section concludes with a discussion of caveats that should be taken into account when drawing conclusions from the analysis.

2.1 CO_2 Inventory

The basic inventory used in this analysis is the 1988 inventory by B.H. Levelton and Associates (1990). However, a number of modifications were made to that inventory.

The most important of these changes was an update for the most recent energy use forecast. This update affected all CO_2 sources, except process sources, gas utilities, solid waste disposal and open burning.[1] Specifically, the base was changed from 1988 to 1989 using the most recent energy demand forecast by the provincial government's Ministry of Energy, Mines and Petroleum Resources (EMPR), and extended to 2010 based on the same forecast. The most significant changes, from a CO_2 perspective, were:

- increased use of natural gas across all sectors (except petroleum refining) with an accompanying reduction in oil-based energy sources;
- reduced dependence on coal-fired power generation in the future;
- much higher fossil fuel and biomass energy use in power generation in 1989 over 1988; and
- increased overall energy use in air transportation.

Also, forest fire emissions of CO_2 were increased from the 1988 figure of 350 kt CO_2 to an annual average of 4300 kt CO_2, a figure that is more representative of the annual average (B.H. Levelton, 1990). Furthermore, we have included these emissions in the provincial totals for this study because, although not an anthropogenic source, they do theoretically represent an opportunity to reduce total provincial emissions.

The implications of the changes to the emission inventory are illustrated in Exhibits 2.1 and 2.2. Exhibit 2.1 compares total emissions for 1988 as presented in the B.H. Levelton report with the

[1] These sources of CO_2 were adjusted to 1989 and extended to 2010 using the implied annual growth rates in B.H. Levelton and Associates (1990).

Exhibit 2.1: Comparison of CO_2 Emission Profiles (k tonnes)

Sector	1988 (BHL)	1989 (ARA)	2005 BHL	2005 ARA	2010 (ARA)
Pulp & Paper	20,765	20,870	22,640	23,240	23,795
Prescribed Burning	13,300	13,065	9,300	9,300	8,475
Road Transport[a]	11,590	12,640	15,970	14,380	14,850
Wood Waste	8,830	8,700	6,620	6,620	6,135
Residential/Agriculture[b]	5,300	5,730	7,770	7,155	7,615
Other Transport	5,820	6,250	6,795	7,865	8,575
Other Industry	5,395	5,595	8,195	6,100	6,520
Wood Products[c]	3,280	2,730	3,400	3,150	3,190
Process Sources	3,240	3,240	3,825	3,825	4,030
Commercial/Admin	2,750	2,750	4,505	4,505	5,690
Gas Utilities	2,410	2,445	2,975	2,975	3,180
Power Generation	1,135	3,700	6,050	4,975	5,070
Waste Disposal	570	575	665	660	750
Sub-Total[d]	84,385	88,290	98,710	94,750	97,875
Forest Fires	350	4,300	4,300	4,300	4,300
Total	84,735	92,590	103,010	99,050	102,175

Notes:
a Includes off-road
b Includes fuel wood
c Excludes wood waste incineration
d Numbers may not add due to rounding

Sources: Appendix C.

Exhibit 2.2: Comparison of CO_2 Emission Profiles (% provincial total)

Sector	1988 (BHL)	1989 (ARA)	2005 BHL	2005 ARA	2010 (ARA)
Pulp & Paper	25	22	22	23	23
Prescribed Burning	16	14	9	9	8
Road Transport[a]	14	14	15	15	15
Wood Waste	10	9	6	7	6
Residential/Agriculture[b]	6	6	8	7	7
Other Transport	7	7	7	8	8
Other Industry	6	6	8	6	6
Wood Products	4	3	3	3	3
Process Sources	4	4	4	4	4
Commercial/Admin[c]	3	3	4	5	6
Gas Utilities	3	3	3	3	3
Power Generation	1	4	6	5	5
Waste Disposal	<1	<1	<1	<1	<1
Sub-Total[d]	99	96	96	96	96
Forest Fires	<1	5	4	4	4
Total	100	100	100	100	100

Notes:
a Includes off-road
b Includes fuel wood
c Preliminary
d Numbers may not add due to rounding

Sources: Appendix C

1989 update, the Levelton and updated forecasts for the year 2005, and the extension of the inventory to the year 2010. Exhibit 2.2 presents the same numbers, expressed as a percent of total provincial emissions.

As indicated by the exhibits, the modifications result in higher (+9%) emissions in 1989 than estimated for 1988 in the Levelton inventory. The increase is largely explained by:

- higher emissions from power generation due to greater natural gas use in 1989 than 1988;
- higher emissions from forest fires; and
- higher energy use in transportation[2] and the residential/agriculture sector.

Comparing estimates for 2005, total emissions are lower (-3%) than the original inventory projection. In fact, the new energy demand forecast is significantly more "CO_2-benign" than the previous forecast, suggesting an increase of only 7% in emissions between 1989 and 2005 compared with a 20% increase projected in the original study. This change reflects greater substitution of oil by natural gas, and lower energy demand in the residential, industrial and road transportation sector than previously expected. (In the case of road transportation, energy savings are associated with a more pronounced shift towards diesel fuel). Power generation emissions are lower because EMPR (1991) assumes coal will not be used.

In both profiles, the dominant sectors remain pulp and paper, prescribed burning, wood residue burning and forest fires, road transportation, and the residential/agriculture sector. Only one sector changed ranking: power generation increased from 1% of total emissions in 1988 to 4% in 1989.

As noted above, the basis for the analysis in this report is the modified profile, as restated in Exhibit 2.3.[3]

2.2 Information Sources

The initial approach to this study was to concentrate on and extract data from the main cross-sectoral studies on global change policies that have been completed in the last two years. These reports and articles were useful in developing long lists of measures for the residential and transportation sectors, and some forest management activities. The reports also provided values for energy savings and costs. Finally, the energy savings (expressed in percentage terms) and

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[2] The difference in the road transportation emissions arise from (i) a discrepancy between EMPR and BH Levelton energy use values for 1988 and (ii) higher 1989 from the EMPR data. Also, energy use in other transportation sectors, especially air, were higher in 1989 than 1988.

[3] Exhibit 2.3 groups the emission sources slightly differently than Exhibits 2.1 and 2.2 to facilitate the analysis of management measures. For example, prescribed burning, wood waste incineration and forest fires are grouped together and the pulp and paper sector includes process emissions from pulp and paper lime kilns.

Exhibit 2.3: Profile Used as Basis for Study

Sector	1989		2005		2010	
	$ktCO_2$	% total	$kt\ CO_2$	% total	$kt\ CO_2$	% total
Pulp & Paper[a]	23,850	26	27,515	28	28,220	28
Prescribed Burning Wood Residue & Forest Fires	26,065	28	20,220	20	18,910	19
Road Transport[b]	12,640	14	14,380	15	14,845	15
Residential/Agriculture[c]	5,730	6	7,155	7	7,615	7
Sub-Total[d]	68,280	74	69,275	71	69,590	68
Other Transport	6,250	7	7,865	8	8,575	8
Other Industry[e]	7,220	8	8,085	8	8,640	8
Commercial/Admin.	2,750	3	4,505	5	5,690	6
Wood Products[g]	2,730	3	3,150	3	3,190	3
Power Generation[f]	2,370	3	2,545	3	2,555	3
Gas Utilities	2,445	3	2,975	3	3,180	3
Waste	575	<1	660	<1	750	<1
Sub-Total[d]	24,335	26	29,780	30	32,580	32
Total[d]	92,615	100	99,050	100	102,170	100

Notes:

a Includes lime kilns and self-generated electricity
b Includes off-road
c Includes fuel wood
d Numbers may not add due to rounding
e Includes process sources
f Excludes self-generated electricity in pulp paper.
g Exludes wood residue inceneration.

Source: Exhibit 2.1.

costs were applied to provincial data on energy use and number of units (e.g., number of light duty vehicles).

The cross-sectoral reports were, however, scant on information on other forestry and forest management measures and on the pulp and paper sector (which was commonly included in a generic section on industry).[4] In these cases, greater reliance was placed on sector-specific articles and reports. Additional measures were added based on study team knowledge and extensions of the literature.

For the pulp and paper sector, a variety of articles were reviewed and discussions with industry association representatives were held. In particular, we have drawn from an initial investigation of energy efficiency and CO_2 impacts completed by Azarniouch of Paprican (1991, draft) and a review document by Herzog and Tester (1991). As discussed below, the two documents take very different perspectives of energy efficiency opportunities in the industry and perhaps illustrate the range of estimates one is likely to encounter in promoting specific measures and policies to encourage CO_2 emission reductions.[5]

2.3 Abatement Estimates

The abatement estimates presented represent *technical* abatement: i.e., the amount of CO_2 that could be reduced (either through reduced emissions or enhanced uptake/absorption). The estimates do not incorporate any consideration of market penetration or uptake of the measure (see caveat (b) in Section 2.5 below). The technical potential reflects the current state of knowledge with respect to technologies and includes those technologies that have a reasonable chance of being applied within the next ten years.

The abatement figures are calculated for the life of the measure. This approach is important for estimating cost-effectiveness because abatement must match the period over which the costs (in particular, capital costs) are amortized. For example, some measures have very large up-front costs, yet generate abatement benefits over a relatively long period (e.g., re/afforestation); by contrast, other measures have much smaller costs and support abatement over a shorter timeframe (e.g., high efficiency lighting). Annual abatement figures are also presented to facilitate direct comparisons of abatement potential.

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[4] The Canadian Pulp and Paper Association, Paprican (which is conducting its own review of CO_2 research) was not aware of any CO_2 research by American industry associations, which is somewhat surprising. One possible reason is the strong focus on and well recognized advances the industry has made in getting off purchased energy.

[5] We understand that Paprican is working on two additional documents that would significantly add to the body of knowledge in this area. The first is a more detailed analysis of the CO_2 issue, essentially an extension of the paper by Azarniouch. The second is a paper that the organization is doing for Energy, Mines and Resources Canada, outlining pulp and paper sector technologies for the future and impacts on CO_2 and energy efficiency.

Finally, abatement estimates are based on 1989 levels of energy consumption and economic activity. This approach provides a basis on which to compare measures, although it would underestimate the total emission abatement potential of the same set of measures over a number of years.

2.4 Cost-Effectiveness Estimates

Cost-effectiveness is defined as the net cost incurred per tonne of CO_2 abated (either through avoided emissions or enhanced sinks/absorption) and, therefore, provides a basis on which to compare the relative expense of each measure. The lower the cost per tonne, the more attractive the measure. Cost-effectiveness values can be negative when the costs of the measure are more than compensated by energy or other savings; that is, the measure pays for itself.

Net cost is composed of three components:

- capital costs (e.g., costs to convert automobiles to alternative fuels);
- incremental operating costs that are incurred each year (e.g., lower or higher maintenance costs associated with alternative fuel vehicles); and
- energy cost savings (e.g., lower fuel costs for alternative fuel vehicles).

Costs are estimated from the perspective of the individual/company undertaking the measure so that "commercially economic" measures can be identified. However, costs do include both those borne by the individual/company undertaking the measure and direct costs of government/public agencies. For example, costs of additional bus purchases to expand the public transit system are included in overall costs on the assumption that these costs would flow through to the consumer in the form of fees and user charges (e.g., transit fares).

All costs are calculated in inflation-free (constant 1989) dollars and discounted to present value terms.[6]

Net cost, then, is calculated as:

PV [Capital costs + Incremental operating costs + Energy cost savings] = Net costs

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[6] Present value is the value, in today's dollars of a future flow of funds (e.g., costs or revenues) of a project or investment. Discounting to present value terms reflects the time value of money (i.e., money that can be invested today and earn a return in the future). A discount rate of 12% is used.

Cost-effectiveness is calculated as:

Net cost -:- lifetime reduction in emissions or increase in absorption of CO_2.[7]

2.5 Caveats and Qualifications

The abatement potential and cost-effectiveness estimates presented below should be interpreted with care. Specifically, the following caveats should be taken into account.

(a) The analysis is based on secondary data sources -- generally, analyses conducted for other jurisdictions. To the extent possible, these data have been modified and adapted to the B.C. context (e.g., for energy use, energy type and prices). However, key items such as percent energy savings and capital costs have been taken directly from the literature. As specified in the Terms of Reference, no original research was undertaken to confirm or modify these estimates.

In most cases, this approach will not create serious errors because the technologies are relatively transferable (as in the residential and transportation sectors). However, as one focuses in on specific industries, (e.g., pulp and paper) approximations are likely to become cruder and the validity of findings from other jurisdictions more tenuous. Ultimately, a set of policy and management measures will have to be considered within the specific characteristics of the individual applications within the province and, consequently, in consultation with industry representatives.

(b) As noted above, we have assumed that all measures are implemented in 1989 and relate specifically to 1989 energy use and levels of economic activity. This approach facilitates calculation of abatement potential and cost-effectiveness. The figures do not incorporate any implementation trends or penetration rates for three reasons:

- penetration rates are not exclusively exogenous -- they can be accelerated or slowed by policy levers and institutional factors;
- this approach enables simple comparisons across measures on the basis of technical abatement potential and cost-effectiveness alone; and
- developing estimates for 1989 instead of future years avoids double counting with measures that may be embedded in the provincial government's energy demand forecast while providing necessary comparative indicators (such as relative abatement potential).

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[7] CO_2 reductions are not discounted as is the practise in some calculations of levelized costs because discounting would distort the environmental impact of CO_2 reductions. Specifically, the benefits of reducing CO_2 by one tonne persist over 120 years (the residency time of carbon dioxide in the atmosphere) and are not "consumed" within the single year of reduction. Not discounting CO_2 reductions is consistent with other studies in this field (e.g., The DPA Group, 1989; VHB Research & Consulting, 1991).

(c) Management measures identified are not additive. Some measures preclude implementation of other measures, as clearly illustrated in interfuel substitution options (e.g., conversion to natural gas *or* propane). Therefore, abatement potential is *not* the sum of abatement for all measures.

(d) We have not considered structural shifts in the economy (e.g., away from energy and CO_2-intensive activities) as management measures, except as they are reflected in the energy demand forecast.

(e) No account is taken of the impact global warming may have on energy use, the CO_2 inventory or the effectiveness of management measures. For example, a rise in summer temperatures may increase energy use for air conditioning and, consequently the potential CO_2 abatement associated with planting trees for shade. Incorporation of climatic feedback effects is unlikely to have significant impacts on the choice of CO_2 management measures in the short term. In considering the longer term, however, the viability of some measures -- for example, greater use of hydroelectric power -- may be compromised by the effects of global warming.

2.6 Categorization of Measures

The management measures were categorized at two points in the study. First, measures included in the long list of management measures were categorized according to abatement potential and cost-effectiveness. "Promising" measures were then identified as those ranked "high" for either criterion and at least "moderate" for the other criterion. The rankings were based on the following definitions:

- Abatement potential

  - high — more than 2% of annual provincial emissions
  - moderate — 0.5% to 2% of annual provincial emissions
  - low — less than 0.5% of total provincial emissions

- Cost-effectiveness

  - high — negative (i.e., cost savings)
  - moderate — between zero and \$10 per tonne CO_2; also measures for which cost-effectiveness could not be calculated or that depended on circumstances specific to actual implementation
  - low — more than \$10 per tonne CO_2

The study then narrowed its focus to the "promising measures". Additional information on possible barriers to implementing these specific measures was collected from the literature and from discussions with a variety of knowledgeable people from industry, government, academia, and environmental groups (see Appendix F). Subsequently, qualitative judgements regarding

the severity of barriers to implementation provided the final criterion on which to categorize measures according to the following definitions:

I. Measures that are commercially economic with low barriers to implementation. This category includes all measures for which the cost savings/monetary benefits to society and to the user exceed the cost of the measure (i.e., the cost-effectiveness value is zero or negative). It most closely represents our interpretation of "measures that are economic in themselves, and can be implemented without significant economic or social cost to British Columbians."[8]

II. Measures that are commercially economic but have high barriers to implementation.

III. Measures that are commercially uneconomic (i.e., costs outweigh benefits and cost savings) with low barriers to implementation.

IV. Measures that are commercially uneconomic with high barriers to implementation.

V. Measures that may emerge from new, as yet unproven, technologies.

[8] Terms of Reference.

3.0 Forests and Forest Management

The "Forests and Forest Management" sector in this study encompasses:

- forests as a source of CO_2 emissions (prescribed burning, forest fires);
- forests as a sink to absorb CO_2 emissions from other sectors; and
- forests as a store of carbon.

The literature covers these issues both individually and as an integrated system by looking at the carbon cycle of the forests. In theory, an undisturbed forest will have a zero net impact on carbon levels -- it will act as neither a sink nor a source (Milko, 1991). Specifically, an undisturbed forest will have a wide range of stands of different maturity. Some older stands may act as a net source of CO_2 as decay and wildfires exceed carbon fixation through growth (although there may be offsetting gains of carbon in the soil). This source, however, would theoretically be absorbed by growth of younger stands elsewhere in the forest.

In the tropics, burning of the forest for agriculture has resulted in the forests becoming a significant source of CO_2. In temperate climates and specifically B.C., land disturbances are largely related to harvest, prescribed burning and wildfires. Comeau estimated net forest accruals and releases in B.C. forests. Based on data from 1981-1986, Comeau estimated that the bolewood component of B.C. forests accumulates about 51.8 million tonnes of CO_2 per year (D. Spittlehouse, B.C. Ministry of Forests, pers. comm.). Removal of bolewood through harvesting or wild fires was estimated at 53 million tonnes CO_2 annually. However, the large error in these two estimates suggests that they are not statistically different. Also, Comeau's analysis did not account for CO_2 uptake in non-merchantable wood (such as branches, bark, roots, snags) and the soil, nor CO_2 emissions from prescribed burning. Accumulation of CO_2 by non-merchantable wood and soil can vary from 10% to 200% of that accumulated in the bolewood, depending on the age of the forests. Prescribed burning in 1988 was estimated to result in CO_2 emissions of 13 million tonnes CO_2 (B.H. Levelton, 1991).

A detailed analysis of the carbon balance for B.C. forests is outside the scope of this study. Ongoing research is underway within the Ministry of Forests and Forestry Canada to better quantify the carbon factors for B.C.'s forests (Comeau, B.C. Ministry of Forests, pers.comm.; Kurtz and Apps, 1992). This work will greatly aid planning for CO_2 management.

3.1 Management Measures

Although the role of the forest as a closed entity is important and its net accumulation of carbon of interest, the focus of this study is the *set* of roles forests and forest management can play in the overall management of CO_2 levels, regardless of their source. What is important, then, is the capacity of forests to increase *overall* storage of CO_2. The mechanisms affecting overall carbon storage can be simplified as:

CO_2 STORAGE = EXISTING STORE + INPUT - OUTPUT

These mechanisms determine the possible management measures to increase CO_2 storage by forests, namely:

(i) protect the existing store of carbon ("EXISTING STORE");

(ii) enhance the forest's accumulation of carbon ("INPUT"); and

(iii) reduce existing sources of emissions ("OUTPUT").

Each of these mechanisms are discussed below.

3.1.1 Measures Related to CO_2 Emissions

The primary sources of CO_2 emissions from forests and forest management are prescribed burning and forest fires. According to the 1988 inventory, these sources accounted for approximately 19% of total provincial CO_2 emissions, as follows:

	k tonnes (1989)	% provincial total
Prescribed burning	13,065	14.1
Forest fires	4,300	4.6
Wood residue incineration	8,700	9.4
Total	***26,065***	***28.1***

Prescribed burning is currently the second largest contributor of CO_2 emissions in the province after the pulp and paper industry. Most of the emissions (83%) are from slash burning for silviculture and fire control, with the remainder from range and wildlife area enhancement. Forest fires (wildfires) account for another 4.6% of provincial CO_2 emissions.

Three abatement options are relevant to prescribed burning and wild fires:

- alternative methods of site treatment and preparation;
- increased harvest efficiency; and
- enhanced forest fire prevention and control.

The first two measures focus on reducing emissions from prescribed burning. Alternative treatment refers to the method of site preparation following harvest. Choices include mechanical treatment and no treatment at all, as well as prescribed burning. Each approach has different implications for CO_2 release. However, selection of the most appropriate method is complicated by a number of factors that are specific to each site. This issue is discussed in more detail in Section 3.2.

Increased harvest efficiency aims to reduce the amount of debris left from logging, thereby converting biomass that fuels slash burning into products with some degree of long term carbon storage. Specific measures include collection and utilization of harvest residues and whole tree chipping.

Nawitka (1990) examined the utilization level of B.C.'s timber harvest. The consultants looked at both increased extraction (i.e., use of harvest residues) and harvesting of stands that were previously avoided. Product opportunities discussed included reconstituted panel products, chemicals and cattle feed, increased use of fibre in chip form for pulp furnishes, fibreboard, etc.

Whole tree chipping or the concept of full tree processing, as indicated by the name, uses all components of the tree as raw material. The process radically reduces the amount of residue left on the forest floor.

From a pure abatement perspective, fewer wildfires means less CO_2 emissions. However, three factors limit the appropriateness of this measure. First, fire prevention and control measures are currently very stringent in B.C. Unlike other provincial and state governments, B.C. generally takes on every fire and has a sophisticated fire identification system in place (R. Clevette, B.C. Ministry of Forests, pers. comm.).

Second, further prevention and control of forest fires raises questions of appropriateness from an ecological perspective. Fire has a role to play in the natural cycle of an ecosystem that protects ecosystem diversity and provides for natural regeneration. Within this context, more rather than less burning could be the most appropriate course of action.

More effort could, conceptually, be devoted to "mop up" -- efforts to put out a smouldering forest fire that has been contained and controlled. "Mop up" involves physically covering the forest fire site to extinguish smouldering fires which would reduce CO_2 emissions directly from eliminating prolonged burning and indirectly by reducing the risk of the fire restarting. Given the large tracts involved in B.C., however, wide-scale implementation of this option is unrealistic for both logistical and cost reasons.

Finally, forest fires caused by human carelessness could be targeted. As about 50% of all fires in the province are the result of campfires, agricultural burning, and incidental forest use, prevention could reduce CO_2 emissions without directly compromising the ecological cycle of a forest stand, or presenting insurmountable logistical and cost impediments. In the area of reducing CO_2 emissions from forest fires, then, only a hypothetical reduction in the area of forests burned by human-caused fires is considered as an abatement measure.

3.1.2 Measures Related to CO_2 Accumulation

The forests are recognized as a potentially major sink for CO_2 emissions in B.C. as trees absorb carbon during growth. Simplistically, plants take carbon dioxide from the atmosphere and convert it into organic compounds by using solar energy and water (i.e., photosynthesis). The

1988 inventory (B.H. Levelton, 1990) estimated that approximately 92,000 kt to 198,000 kt of CO_2 are accumulated each year by B.C. forests.[1]

Measures to further enhance forests as a carbon sink have been widely addressed in the literature and generally include:

- planting more area in forests;
- planting trees in specific locations; and
- enhancing productivity.

Planting More Area in Forests

In B.C., managed forests are already in a cycle of harvest and regeneration. The biggest opportunities for replanting lie in (i) NSR (Not Sufficiently Restocked) lands and (ii) marginal agricultural land.

Approximately 845,582 ha. of Crown land are currently classified as NSR. Of this total, 553,145 ha. are on good and medium land, 266,683 ha. on poor land and 25,754 ha. on low land (B.C. Ministry of Forests, 1988). Replanting on good and medium sites only are considered viable management options.

Foresting marginal agricultural land reaps benefits by replacing low biomass with high biomass land cover. In addition to greater levels of above-ground biomass, Birdsey (as reported in Sampson, forthcoming), shows that timberland protects carbon in the soil by minimizing soil erosion and increasing the root density in the soil more than grassland or cropland. Marginal agricultural land has, for the purposes of this study, been defined as land in the Agricultural Land Reserve planted in forage, grains, horticultural crops, grass, or pasture with a land capability classification of class 5-7 inclusive.

Planting Specific Locations

Most of the comprehensive studies for CO_2 management have included planting trees in specific locations to increase biomass and to reduce energy demand for: (i) space heating (by providing wind shields); and (ii) cooling (by providing shade and breaking up "urban heat islands").

Lashof & Tirpak (1990) concluded that "an urban tree is about 15 times more valuable than a forest tree in terms of reducing CO_2 emissions". OTA (1991) estimated that the planting of 100 million trees throughout the United States could avoid the release of 8.2 million tonnes carbon per year from fossil fuel use for space cooling. Other location-specific benefits of trees are as snow fences along highways and wind breaks in agricultural regions.

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[1] The range of estimates depends on the expansion factor used to convert bolewood and bark to total biomass inclusive of leaves, branches, etc.

In B.C., the majority of the population live in the moderate climate of the southern portion of the province and, consequently, the demands for space heating and cooling are not likely to be as significant as in the United States or even the rest of Canada. Most highways, with the possible exception of parts of the Coquihalla Highway, are naturally protected by forests, and the geography of the province mitigates the need for wind breaks on most agricultural land.

As a point of reference, however, we have included in the long list of management measures planting of 600,000 "urban trees". This figure represents 50% of the 100 million included in the OTA study, prorated by population differences between the U.S. and B.C.

Enhancing Productivity

Enhancing forest productivity through intensive forest management techniques could accelerate rates of growth of individual trees and increase total biomass accumulated in the forest. Intensive management practices include:

- site-specific species selection
- spacing
- weed and pest control
- fertilization
- irrigation
- genetically improved seedlings.

The benefits of these practices include increased rates of growth and, consequently, greater biomass accrual and CO_2 uptake. Estimates of potential increased growth vary widely: several sources cite growth enhancement of 25% to 60% over conventional management practices (OTA, 1991; Lashof & Tirpak, 1990),[2] although estimates for B.C. are considerably lower at 4 to 12% (see Appendix A) .

Intensive management is not relevant to all forested lands. Indeed, practices related to planting (e.g., genetically improved seedlings, site-specific species selection) are appropriate only to replanted areas. Other management techniques are implemented at the tree age of 15-20 years. To estimate potential enhancement of CO_2 uptake from enhanced tree growth, it was assumed that intensive management techniques would be applied in:

- all NSR lands (on good and medium sites) that were restocked in the replanting measure described above;
- managed forest stands in age class 1 (i.e., less than 20 years old); and
- newly forested marginal agricultural land according to the measure described above.

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[2] Enhanced growth estimates refer to increase in merchantable timber rather than total biomass. However, it is reasonable to attribute a value within that range to increased growth in biomass.

3.1.3 Measures Related to Carbon Storage and Harvest

As discussed in Section 3.1.2 above, forests represent a store of carbon. Extending this concept has raised the suggestion that logging of old growth stands should, on the premise of CO_2 management, be restricted. On the other hand, some argue that growth rates and, hence, CO_2 uptake in immature forests far exceeds that for mature forests and that newly replanted forests provide better CO_2 management.

The validity of these two arguments hinges on the timeframe used for the analysis and the fate of harvested forest resources. At a theoretical level, 100% utilization of all harvested biomass in durable, long term products (e.g., lumber for buildings) accompanied by 100% restocking could augment CO_2 sequestering over a full rotation cycle. However, these two conditions are unrealistically stringent, a fact that has been recognized in the literature.

The Oregon Task Force on Global Warming (1990), for example, estimates that young replacement stands "will not reach carbon storage levels equivalent to that of old growth for about 250 years". This statement is corroborated by OTA (1991): citing a study by Harmon et. al. (1990), OTA reports that second growth forests reach the same level of carbon storage as an old growth stand only after two centuries and, over a 60-year period, sequesters about 350 tonnes/ha less than old growth stands.

The divergent carbon storage pictures for new and mature stands are attributable to several factors, the most important of which are:

- ***Partial utilization of forest biomass.*** Only a portion of forest biomass is actually harvested for product manufacture. First, a considerable amount of biomass is left on the forest floor to be burned or decay, thus generating CO_2 emissions. Further wood residue is generated by sawmills and other wood products industries, and paper manufacture. For example, less than 50% of the wood chips are held in the kraft product -- the remainder in the form of black liquor is burned as a waste fuel for process steam and electricity.

- ***The duration of carbon storage in forest products is relatively short.*** Row et.al. as reported in Sampson (forthcoming) shows the disposition of carbon 100 years after forest harvest (for 60 year rotations) as:

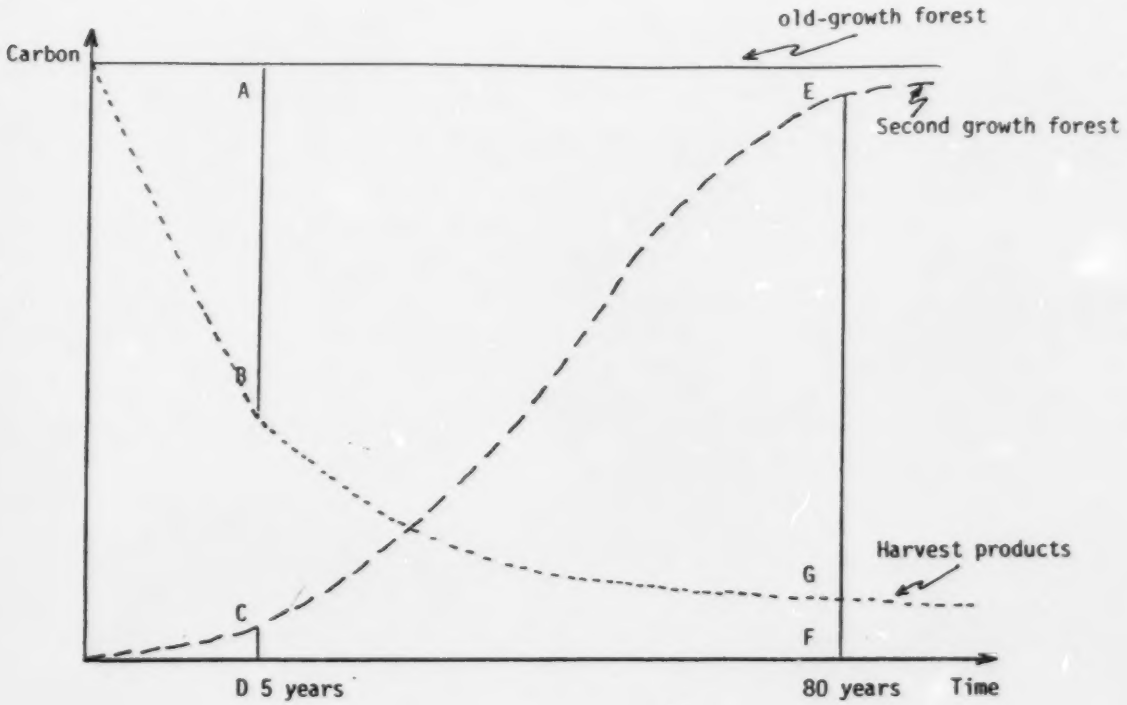
- in use (long term storage):	10% of harvest
- combustion as fuel:	37% of harvest
- landfill (post-consumer products):	28% of harvest
- lost (burned, decomposed,etc.):	25% of harvest

Thus, under current fibre use patterns, only 10% of original carbon remains stored after 60 years. A full 62% is likely emitted as CO_2 (combustion as fuel, lost) and another 28% is landfilled, which may or may not decompose (OTA, 1991).[3]

The trade-offs between CO_2 uptake and CO_2 storage in old growth stands are illustrated in the following schematic.

The total amount of carbon sequestered in mature stands is indicated by the solid line at the top of the diagram. The storage of that carbon when harvested is indicated by the dotted line. The loss of carbon to the atmosphere is the difference between these two lines. The loss is greatest at first as waste biomass is burned (prescribed burning and wood residue incineration) and non-durable products make their way to landfills or incinerators.

The broken line represents carbon storage by second growth forests. In the early years, loss of carbon from harvesting (distance AB) is greater than the uptake by second growth stands (distance CD). At some point the loss and gain even out, with an overall gain in the latter years of a rotation. (For example, at 80 years, distance EF has been accumulated, just short of the mature stand carbon storage. Offsetting this short fall is the amount of carbon sequestered in durable wood products -- the distance GF).



[3] This pattern of fibre use could be modified to improve carbon storage (e.g., greater paper recycling). Relevant measures are discussed below and in Section 4.

The magnitude of the gain in latter years depends on the amount of harvested biomass that remains intact and acts as long term carbon storage, and the productivity and density of second growth forests. These factors, plus the time profile of carbon loss and uptake, will also determine whether -- or over what timeframe -- losses are eventually offset by gains.[4]

The schematic illustrates two key points in developing a set of CO_2 management measures. First, existing timber stands do provide an effective method of storing carbon, although they contribute only marginally to uptake of current emissions. To avoid additional contributions to ambient CO_2, then, harvesting should be judicious. Second, CO_2 management can be enhanced by increasing long term storage of carbon through more intensive biomass utilization and allocation of biomass resources to durable products.

These considerations generate the following management possibilities:

- ***Increase utilization of harvest residues and wood residues.*** This measure falls into the category of "more intensive utilization of biomass resources". It would reduce demand for new harvest by using wood residues from pulp and paper and wood products mills in traditional product lines, new products, or in substituting for fossil fuels. Possibilities include:

  - producing fuel pellets for domestic residential heating and for export;
  - export for electricity generation;
  - electricity generation in central power stations; and
  - use in traditional or new paper and wood products.

  The key to increased utilization of biomass as an energy source is replacement of carbon fuels by an energy resource that would be burned (i.e., would release CO_2) in any event. For example, the wood products industry uses approximately 50 PJ of fossil fuel annually, creating about 2750 kt of CO_2. It also incinerates wood residues generating in the order of 8800 kt per year, for total CO_2 emissions of about 11,500 kt per year. If fossil fuels could be substituted by wood residues, the CO_2 emissions from those fossil fuels would be eliminated and total emissions would fall to 8800 kt per year.

  The recently announced Smoke Management Policy could affect the amount of wood residue burned in beehive burners. The net effect on CO_2 levels will depend on the alternative method of disposal/use. As discussed above, use of wood residues as an energy source will generate CO_2 savings, although the level of those savings will be much higher where high carbon fossil fuels (as opposed to hydroelectricity) are displaced.

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[4] The diagram is illustrative only. The actual rates of growth etc. will depend on species, product types, waste utilization, and other variables.

Export of wood residues can be a sensitive issue because it raises concern that B.C. would simply be exporting an environmental problem for which it is responsible. Export of wood residues could indeed degenerate into such a case *unless* those exports are made under certain conditions: that the residues are used to substitute for high carbon fuels. If, for example, wood residues are converted into fuel pellets and exported to Alberta to be used in the place of coal-generated electricity, *global* emissions of CO_2 would fall by the CO_2 content of the displaced coal (analogous to the wood products example above).

This export measure makes sense only because global warming is related to *global* concentrations of CO_2; the source of those emissions is not important. Thus, CO_2 management involves taking up the best opportunities for CO_2 abatement, regardless of where those opportunities exist. In this example, exporting to Alberta to substitute for coal (with a CO_2 factor of 90 kt/PJ) would generate more significant CO_2 reductions than substituting for hydroelectricity in B.C. (with a much lower CO_2 factor).

- ***Emphasize manufacture of durable products and increase recycling.*** By increasing the lifetime of forest products, carbon is stored for longer and the demand for new harvest is reduced, thereby preserving the natural storage of carbon in forest biomass. The options for increased emphasis on durable products does not, however, have the same significance to the B.C. wood products industry as it may in other jurisdictions because the nature of the resource has resulted in a generally durable mix of products (e.g., lumber for construction).

  Opportunities do exist to increase product life and reduce demand for virgin pulp in the paper products sector through increased recycling. Recycling not only protects virgin stores, but may require less energy to process. Both contribute to CO_2 management.

- ***Increase end-use efficiencies.*** Modifying building designs, using efficient fuel wood burners, and minimizing packaging could reduce the demand for forestry products, thereby protecting natural storage of carbon and reducing energy expenditures in the production of those items.

- ***Introduce biomass plantations for specific products*** that (i) sequester carbon on a long term basis or (ii) can replace fossil fuels with a net reduction in CO_2 emissions per unit energy. Two possibilities are biomass energy crops and food crops. Energy from biomass has received considerable research attention, including the ENFOR program of the federal government and the U.S. Department of Energy's research program. The main forms of energy from wood biomass are:

  - electricity;
  - methanol; and
  - ethanol.

Biomass-fired electricity is gaining popularity in California where total burning capacity in excess of 20 million m^3 can be expected (Nawitka, 1990). Also, research has indicated that adaptation of the integrated-gasifier-combustion-turbine technology (combined cycle or aeroderivative turbines) from coal to biomass is promising.

In the B.C. context, the benefits of biomass-fired electrical generation would only lie in substituting fossil fuel fired plants. Of course, any CO_2 benefits depend on continual rotation and replanting fast growing biomass species that, during growth, effectively take up CO_2 released during combustion.

Methanol and ethanol are liquid fuels that can be produced from biomass with principal applications in transportation. Methanol is produced from a synthetic gas from biomass using pyrolysis or oxygen blown gasification and then converted to methanol using catalysts. Production and use of ethanol has largely occurred in developing countries using sugarcane as a feedstock, although the U.S. Department of Energy is conducting research on ethanol from corn. The CO_2 abatement potential from biomass-derived energy sources is examined in each of the relevant end-use sectors, namely power generation and transportation.

Food from forest resources is a revolutionary idea that is only beginning to attract research. The concept involves replacing annual crops such as corn and soybeans with specially managed woody crops domesticated and grown for protein, carbohydrates, and oils (Rutter, 1988).

3.1.4 Summary of Management Measures

Forests and forest management offer numerous ways to manage CO_2 levels in the province. The methods encompass:

- decreases in direct CO_2 emissions from the forests;
- increases in or protection of carbon storage; and
- reductions in fossil fuel use by substituting the renewable forest resource as an energy source or by directly reducing energy requirements (a form of energy conservation).

In some cases, a management measure can affect CO_2 levels in more than one manner. For example, foresting specific locations (e.g., "urban forestry") will take up CO_2 as well as reduce the amount of energy required for air conditioning. The manner in which each of the measures identified above can affect CO_2 levels is summarized in Exhibit 3.1.

It should be emphasized that Exhibit 3.1 provides a long list of potential measures. Some of these measures are as yet only roughly conceptualized (e.g., food crops from forest resources), some have been the subject of research but are still attended by considerable risk (e.g., bioenergy) and still others have technological barriers (e.g., enhancing end-use efficiencies, increasing recycling).

Exhibit 3.1: Forests and Forest Management Measures

Management Measure	Increases or Protects Carbon Storage	Decreases Direct CO_2 Emissions	Substitutes/Reduces Fossil Fuel Use
Measures Related to Emissions			
Alternative site treatment	*	*	
Utilization of harvest residues	*	*	
Whole tree chipping	*	*	
Human-caused fire prevention	*	*	
Plant NSR lands	*		
Plant marginal agricultural land	*		
Plant specific locations	*		*
Enhance forest productivity	*		
Measures Related to Storage & Harvest			
Fuel Pellets			
Export for cogeneration			*
Central power stations			*
Other product utilization	*	*	
Recycling	*	*	*
End use efficiencies	*		*
Bio-energy plantations		*	*
Wood-based food crops	*		

Not all measures can be applied to B.C.'s forest resources with the same abatement impact as in other jurisdictions and the significance of measures differ depending on the timeframe considered (e.g., reforestation offers a stop-gap measure over the first 80 years while bioenergy plantations provide an ongoing source of CO_2-reducing fuel). Finally, some measures face attitudinal or institutional barriers (e.g., preventing human-caused forest fires) and not all measures are economical. The list does, however, provide a starting point for a more critical assessment of CO_2 management options.

3.2 Abatement Potential

The summary statistics for technical potential for forests and forest management measures are presented in Exhibit 3.2. Excluded from this list are the following measures:

- Central power stations (because data are not available);[5]
- Recycling, which is covered in the section on pulp and paper;
- Enhanced end use efficiencies (because evaluation of the potential for abatement cannot be assessed without consideration of the fates of B.C.'s exports, a task that lies outside the scope of this study);
- Bioenergy plantations which is covered in the appropriate end use sections; and
- Plantations for wood-based food crops (because the technology is too premature and falls into the list of "new technologies").

The figures in Exhibit 3.2 depend, in a number of cases, on assumptions because estimates were not available in the literature and many options encompass exploitation of new product opportunities. In lieu of specific market studies, we have assumed use of 10-20% of current levels of residues and wastes to indicate the magnitude of potential abatement. The specific assumptions used are noted in the exhibit.

As shown in Exhibit 3.2, measures with the most significant abatement potential are those related to planting. Restocking all good and medium NSR lands could accumulate over 3 million tonnes CO_2 a year. Combined with planting of all marginal agricultural land, up to 5 million tonnes could be absorbed annually.[6]

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[5] In B.C., CO_2 benefits from diverting wood waste to central power stations are not as significant as in other jurisdictions because the plants would substitute grid power which is dominated by hydro-electricity. Use of wood wastes in fuel pellets, export for cogeneration, or in product use likely yield greater CO_2 benefits.

[6] As noted elsewhere, estimates of carbon uptake depend on various growth rates and expansion factors, variables over which there is considerable debate. The range of abatement estimates reflects this uncertainty.

Exhibit 3.2: Abatement Potential & Cost-Effectiveness of Forests and Forest Management Measures

	Life of Measure	Annual\CO_2 Reductions		Lifetime CO_2 Reductions (millions t)	PV Net Costs ($ million)	Cost-Effectiveness ($ per tonne CO_2)
		kt/year	% 1989 Provincial Emissions			
Measures Related to Emissions						
1. Alternative site treatment	80	cannot generalize		44	b	b
2. Utilization of harvest residues[a]	20	2210	2.4	22	>0	>0
3. Whole tree chipping[c]	10	2610	2.8	5	?	?
4. Human-caused fire prevention[d]	10	540	0.6			
Measures Related to CO_2 Accumulation[e]						
5. Plant NSR lands	80	2360-3020	2.5-3.3	188-242	440-550[f]	2-3
6. Plant marginal agricultural lands	80	750-865	1.0	60-77	90[g]	1-2
(with pastureland[j]	80	1790-2290	1.9-2.5	143-183	210[f]	1-2
7. Plant specific locations	80	125-130	0.1	9	9	1
8. Enhance forest productivity[j]	80	255-965	0.3-1.0	20-77	200[h]	3-10
(with pastureland[j]	80	295-1125	0.3-1.2	24-90	225	3-10)
Measures Related to Storage & Harvest						
9. Fuel pellets -- domestic[k]	20	120	0.1	2	?	?
10. Fuel pellets -- export[l]	20	335	0.4	7	b	b
11. Export for co-generation[m]	10	1580	1.7	16	b	b

Exhibit 3.2: Abatement Potential & Cost-Effectiveness of Forests and Forest Management Measures (Cont'd)

Notes

a Assumes 10% or 1.1 million m^3 of harvest residue utilized, based on residue estimates by Nawitka (1990). Assumes utilization in durable products. Life of measures base on life of capital required.

b Economic viability depends on specific products, locations and markets. Expect some viability (Nawitka, 1990).

c Assumes 20% reduction in harvest residues

d Assumes 25% reduction in human-caused fires.

e Ranges reflect different assumptions regarding carbon uptake (see Appendix A). Life of measure based on one rotation.

f Excludes harvest value of timber, but this has little effect on total costs.

g Excludes harvest value of timber and land costs.

h Excludes value of incremental harvest.

i Range includes different estimates of additional growth attributable to intensive management, as well as different assumptions regarding carbon uptake.

j Includes 50% of pasture and grasslands (see Appendix A).

k Assumes 30% increase in use of fuel wood as residential heat source.

l Assumes 5% of wood waste currently incinerated is diverted to pellets for exports. Excludes energy required for product manufacture.

m Assumes 5% of expected California demand is met by B.C.. CO_2 emissions based on 185 kt CO_2/PJ for U.S. electricity (OTA, 1991).

Source: Appendix A

However, planting NSR and marginal agricultural lands is a stop-gap measure. Once those lands are planted, we have assumed they enter the harvest-regeneration cycle so that the CO_2 accumulation figures in Exhibit 3.2 are valid for the first 80 years (i.e., one rotation) only. This option differs from energy conservation measures that can be undertaken every year with CO_2 pay-offs. Nevertheless, the absolute amount of potential abatement from restocking is noteworthy as an interim measure.

Utilization of forest residues and more intensive use of wastes also offer opportunities for reducing CO_2 emissions. For example, diverting 10% of harvest residues (about 1.1 million m^3) to durable products could reduce emissions by about 2,210 kt per year; a 5% diversion of wood residues to export (fuel pellets) could reduce emissions by about 335 kt per year. Product opportunities must be considered in much greater detail than is possible here. However, the figures in Exhibit 3.2 do indicate potential for CO_2 emission reductions. Utilization of residues and wastes may also reduce the demand for new harvest, thus protecting carbon storage and avoiding attendant energy expenditures. These considerations are not included in the estimates of CO_2 abatement in Exhibit 3.2.

Of relatively little importance is the measure to plant specific locations. As described above, the purpose of this measure is to reduce energy use for cooling and heating. The low CO_2 abatement figure is driven in large part by the dominance of hydroelectric power and the resulting low CO_2 factor for electricity in the province.

We are not able to derive estimates for alternative site treatment options as the most appropriate method of site preparation is highly dependent on site-specific factors. These factors include the type of burn or type of mechanical treatment used, slope of the site, soil composition, characteristics of harvest residues (e.g., between coarse and fine fuels), and timeframe. Although better management of site treatment could offer CO_2 abatement opportunities, it would be unrealistic to generalize as to *the single* most appropriate approach.

For example, a very hot burn is likely to release more CO_2 than a light burn because a hot burn will release carbon from coarse high carbon fuels; a light burn, on the other hand, will largely be limited to the finer fuels (e.g., leaves, twigs) that would decompose naturally (i.e., microbial decomposition) with no site preparation at all, thereby releasing the same amount of carbon over a similar time frame. Mechanical treatment could also release more carbon than a well managed prescribed burn; some mechanical treatments disturb the forest soil, and gather debris into a pile which can accelerate decay. In addition, the choice of site treatment method will affect the productivity of new growth forests. In some instances, it is conceivable that higher CO_2 emissions during site preparation could be more than offset by enhanced regeneration, the potential impact of which is illustrated by measure #8 in Exhibit 3.2: "Enhancing productivity" (H. Kimmins, University of B.C., pers. comm.).

The relatively significant CO_2 savings from restocking NSR lands suggests a management measure that has been almost implicit: ensuring rapid and successful regeneration of managed forest sites. Replanting has long been a concern among foresters and the public. This concern is reinforced by the role of forests as a carbon sink. Specifically, maximizing growth of second

generation stands helps offset the loss of carbon from the use of forest harvest and could extend the overall net accumulation of CO_2 by the forests, thereby compensating for emissions elsewhere in the system.

3.3 Cost-Effectiveness

Cost-effectiveness of forest measures can be roughly broken into two groups: those for which there is potential for overall savings and those that clearly entail net expenditures (see Exhibit 3.2). Included in the first category are most of the measures related to utilization of harvest and waste residues. In these cases, economic viability will depend on specific products, locations, and markets and the extreme uncertainty of these opportunities precludes any generalized economic analysis.

However, Nawitka (1990) identifies a number of products from residues some of which could be profitable (including small log sawmilling and export of wastes for cogeneration). However, many of the utilization opportunities are rated "possible"; that is, "product price increases, lower or incentive costs, or a moderate combination of the two are needed to make the venture feasible".

Falling into the second category -- net expenditures -- are all measures related to CO_2 accumulation. The cost of restocking good and medium NSR lands totals about $440-550 million, with an additional $90-210 million for marginal agricultural land (excluding land costs). These estimates result in a small but positive cost of $2-3 per tonne CO_2 removed for both NSR replanting[7] and planting of marginal agricultural land.

3.4 Climate Change and Forest Management

Although this study focuses on measures to reduce the potential for climate change by managing carbon dioxide levels, the measures outlined for the forest resource should ultimately be considered in the context of possible effects that climate change may have on the health and composition of temperate forests. A recent symposium on climate change and management of Pacific Northwest forests recommended that change be accepted as inevitable and that strategies be developed for managing forests under a changed climate (Spittlehouse, 1991).

A number of the recommendations forwarded by that symposium are fully consistent (and in some cases overlap) with CO_2 management measures discussed above and in other sections of this report. Two of the most fundamental are:

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[7] Please note that there are considerable variations around these figures related to variable planting costs and growth rates. For example, we have used an average planting cost of $425/ha (from a range of $379-$529/ha.) and seedling costs of $.25 each (from a range of $.14-$.40) (R.Brown, B.C. Ministry of Forests). The figures do not include the harvest value of the new forests. However, when discounted over 80 years, this value has little impact on cost-effectiveness; in particular, it does not make the measure "pay".

- recognizing the value of forests as a carbon sink and incorporating this and other environmental values into forest management policies and practices; and

- protecting the overall health of the forests through monitoring, reduction of risk of loss, appropriate harvest and regeneration practices, and better utilization of fibre.

3.5 Summary

The main conclusions that can be drawn from the above analysis are:

- Replanting NSR and marginal agricultural lands could significantly contribute to CO_2 management in the province. These measures will be costly: although small on a per tonne CO_2 basis (less than $10), the total cost of replanting NSR and agricultural lands is about $500 to $750 million. Re/afforestation represents a one-time increase in carbon absorption.

- Utilization of harvest residues and wood residues (from wood products and pulp and paper mills) could both yield CO_2 benefits. In most cases, however, the profitability of the venture will be highly dependent on local conditions, markets, prices, etc.

- Province-wide generalizations as to the most CO_2-benign method of site treatment are not defensible. However, gains from tailoring treatment methods to the specific characteristics of the site may be possible.

- The rates of carbon accumulation by new forests underscore the importance of rapid and successful reforestation of managed forests. In this context, the choice of site treatment method will have to weigh direct CO_2 releases from treatment against the potential incremental growth (and carbon accumulation) made possible by appropriate site preparation.

- Old growth forests provide a good store of CO_2 and judicious harvesting, efficient use of wood products and wood residues contribute to protecting this store.

4.0 Pulp and Paper

4.1 CO_2 Emissions

According to the 1988 inventory of emissions (B.H. Levelton, 1990), the pulp and paper industry was the largest source of CO_2 in 1988 and is projected to maintain that position through to the year 2005. CO_2 emissions from the pulp and paper industry in 1989 are estimated to be:

Source	k tonnes CO_2	% provincial total
Lime kilns	1,650	1.7
Chemical recovery and power boilers	20,870	22.5
Self-generated power	1,330	1.4
Total	***23,850***	***25.7***

It is not surprising that the pulp and paper industry plays such a significant role in the emission profile. It is one of the major industries in the province and uses inherently energy-intensive processes. Indeed, the industry is the single largest consumer of energy in the province. The dominant energy sources in the pulp and paper industry are self-generated pulping liquors and hog fuel, natural gas, oil, and electricity from the main grid.

4.2 Management Measures

The main body of literature on CO_2 management measures reviewed for this study is thin with respect to specific measures for the pulp and paper industry and usually subsumes pulp and paper under general industry measures. The reason for this slight treatment is the dominance of other sectors in the emission profile (e.g., power generation and transport) in most jurisdictions.

However, the pulp and paper industry in Canada has recognized its role in the CO_2 issue through the Global Climate Change Committee of Canadian Pulp and Paper Association (CPPA). The CPPA has released a brief position paper and the Pulp and Paper Research Institute of Canada (Paprican) is currently working on a more detailed study on energy efficiency opportunities as they relate to CO_2. A paper on a related theme is also being developed for Energy, Mines and Resources Canada. Unfortunately, neither was completed or available during the time period for this study.

Based on the documentation available, CO_2 abatement options for the pulp and paper industry fall into three categories:

- energy efficiency;
- interfuel substitution; and
- process changes.

A list of possible CO_2 management measures, taken from the Energy Conservation Opportunities program of the Energy Committee of the CPPA, and from the literature is presented in Exhibit 4.1, broken into each of these three categories. Although illustrative of specific measures, the energy conservation measures are not necessarily representative of the industry as a whole.

Energy Efficiency

The pulp and paper industry, like many other energy-intensive industries, has made dramatic improvements in energy efficiency over the last two decades, spurred in large part by the oil shocks of 1973 and 1977. Purchased energy per unit output has declined about 26% since 1972 (CIPEC, 1990). Notwithstanding these changes, energy conservation opportunities still exist, although their economic attractiveness tends to be sensitive to prevailing energy prices.

Interfuel Substitution

Interfuel substitution possibilities call for careful interpretation in the pulp and paper sector. A basic CO_2 ranking for fuels used in the pulp and paper sector in terms of CO_2 per unit of heat is:

- purchased electricity (lowest CO_2 factor)
- natural gas ↓
- oil ↓
- coal (highest CO_2 factor)

The position of hog fuel and pulping liquors within this ranking depends on the interpretation of their alternative fates. Both fuels have very high carbon content -- 81 kt/PJ and 107 kt/PJ, respectively (compared with 71 kt/PJ for heavy fuel oil). However, much of the literature treats substitution of fossil fuels by hog fuel and pulping liquors as a CO_2 *abatement* measure for the following reasons:

- these waste products would be burned or otherwise disposed of (biodegrade) over time, thereby releasing an equal volume of CO_2; or

- much of the literature assumes forest regeneration, so that CO_2 emitted from harvest materials is taken up again during growth, resulting in no net CO_2 release over the longer term.

These premises, in general, also hold in the B.C. industry so that hog fuel and pulping liquors are included at the top of the CO_2 ranking. The final ranking of fuels used in this study for the pulp and paper sector is:

- hog fuel and pulping liquors (zero CO_2 factor)
- purchased electricity ↓
- natural gas ↓
- oil ↓
- coal (highest CO_2 factor).

Process Changes

Given the B.C.pulp and paper industry's structure and pattern of energy use (see below), process changes take on particular importance when discussing CO_2 management options. Process changes include modifications to existing processes and introduction of new technologies. Of particular interest is the role of recycling; recycling consumes significantly less energy per unit output and extends the use of the raw material (an abatement option in and of itself -- see Section 3.1.3).

4.3 Abatement Potential

We made several attempts to develop abatement and cost estimates for the measures listed in Exhibit 4.1. However, it became apparent that the resulting figures would be highly misleading. For example, we reviewed and analyzed numerous Energy Conservation Opportunity reports (ECO's) published by the Canadian Pulp and Paper Association. ECO's are a collection of summaries of energy saving projects that have been undertaken by mills and selected by committee for their degree of innovation and originality. The purpose of the summaries is to share information and ideas and to promote energy conservation in the industry. The data available in the ECO's does enable the type of manipulations required to estimate CO_2 abatement and costs. However, the key factors in those manipulations -- energy savings and capital costs -- are very location- and application-specific. Extrapolating those figures to other mills, therefore, is unrealistic and would be misleading. Furthermore, the list of measures is not complete.

Instead, we consider abatement potential at a more aggregated level. Specifically, we explore whether the types of changes seen in the past are likely to be achieved in the future.

Exhibit 4.2 estimates the CO_2 abatement implications of past energy use trends. As indicated, energy-related CO_2 emissions fell from about 1 tonne/ADMT in 1972 to 663 kg/ADMT in 1989, a decline of almost 36%. These reductions in "CO_2 intensity" are attributable to two factors:

- a decline in overall energy intensity of about 9% over the 17 year period; and
- a significant decline in fossil fuels of about 36% over 17 years in favour of purchased electricity and self-generated fuels (i.e., hog fuel and pulping liquors).

The switch to purchased electricity and self-generated fuels yields reductions in CO_2 because:

- electricity is generated using primarily hydro and nuclear options within Canada (accounting for about 75% of power production) and so has a lower CO_2 content than either oil or natural gas (Energy, Mines and Resources Canada, 1987); and
- hog fuel and pulping liquors are credited with a zero CO_2 factor.

Exhibit 4.1: List of Management Measures in the Pulp and Paper Industry

Energy Efficiency

- Energy efficient motors
- Variable speed drives
- Energy efficient lighting
- Heat recovery
  - heat recovery from SGW decker white water
  - recovery and reuse of paper machine white water
  - boiler blow down heat recovery
  - heat recovery from E1 bleach filtrate
  - recovery of machine press water
  - blow heat recovery on batch digesters
  - heat recovery hood on hot end of kiln
  - recovery of heat from flue gas
- Minimization of losses
  - insulating stock chests and tanks
  - reduction of lime kiln heat losses by low emissivity paint
  - steam trap upgrade
- Closing up of processes
  - reduce fresh water usage
  - eliminate fresh water use on bleach decker
  - white water closure
  - optimize filtrate recycle in bleach plant
- Energy controls
  - improve paper machine moisture control
  - computer control on batch digesters, recovery and power boilers, paper machines
  - improve soot blowing system
- Heat integration (pinch technology)

Interfuel Substitution

- Replace oil and coal with natural gas
- Replace fossil fuels and purchased electricity with self-generated fuels

Process Changes

- Digestion
  - continuous digestion
  - displacement heating
- Evaporation
  - multi-stage MEE
  - VRE
- Impulse drying
- Increase paper machine pressing load
- Reduction of lime mud moisture
- Install high density chain in lime kiln
- Advanced pulping processes
- Increased recycling of post-consumer products

Extrapolating these energy use trends suggests a further 18% reduction in CO_2 to 546 kg/ADMT by the year 2000, as shown in the last column of Exhibit 4.2. This decline could represent a drop of about 4400 kt CO_2 per year, almost 5% of the provincial total in 1989.

Extrapolations inevitably beg the question: is the past an appropriate indicator of the future? Do energy saving and fuel substitution opportunities still exist? A review of the literature and information from industry sources suggest that such opportunities are available. For example, over 250 ECO's have been published over the last 10 years, documenting energy saving opportunities. For example, Azarniouch (1991) in an internal report for the CPPA Committee on Global Climate Change examines 23 different energy conservation measures, based on ECO's. Assuming potential implementation by 50% of industry capacity in Canada, he estimates energy savings as 57 TJ/yr to 2084 TJ/yr per measure.

Articles in the journals describe other opportunities. Herzog and Tester (1991) identify four areas for energy conservation (digestion, evaporation, drying, and heat integration) where new technologies could reduce *sector* energy use by some 15%. New plants in Sweden have been constructed that use *only* self-generated fuels during normal operation, virtually eliminating purchased fuels (Poyry, 1986). Riemer (1983) makes the point that "there are still a number of practical, non-capital opportunities available" for energy conservation.

The statistics in Exhibit 4.2 describe the Canadian industry as a whole. The next question is whether continued energy conservation and, particularly, interfuel substitution opportunities still exist in B.C.

Exhibit 4.3 compares the mix of energy sources in 1989 in B.C. mills with those in Ontario and Quebec.[1] As shown, B.C. currently derives a larger percentage of its energy requirements from energy types at the top of the CO_2 hierarchy described above (i.e., more CO_2-benign fuels). Specifically, over 67% of energy consumption comes from self-generated fuels as opposed to 44% and 34% in Ontario and Quebec, respectively. The difference is due partly to the dominance of kraft mills in the province. In B.C., only 22% of requirements come from fossil fuels as opposed to about 36% in the other two provinces. With completion of the Vancouver Island gas pipeline in 1990, most of the fossil fuel consumption in B.C. will be in the form of natural gas.

Furthermore, CO_2 emissions related to purchased electricity are low in B.C. compared to Ontario because of the dominance of hydro power in purchased electricity. (Roughly weighted average CO_2 factors for electricity generation from all sources (i.e., hydro, coal, gas, etc) in B.C. is 12.3 t/TJ compared with 23.4 t/TJ for all of Canada.)

From the perspective of interfuel substitution measures to reduce CO_2 emissions in B.C., then, future opportunities are more limited than in other provinces. However, the energy profile does

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[1] These three provinces account for approximately 81% of national energy consumption in the pulp and paper industry (Soulsby, 1990).

Exhibit 4.2: Energy Use & CO_2 Trends in Pulp & Paper (Canada)

Fuel Type	1972 Energy Use (GJ/ADMT)	1972 CO_2 Emissions[a] (kg/ADMT)	1989 Energy Use (GJ/ADMT)	1989 CO_2 Emissions[a] (kg/ADMT)	2000 Energy Use[b] (GJ/ADMT)	2000 CO_2 Emissions[a] (kg/ADMT)
Pulping Liquor	10.3	0	10.8	0	11.1	0
Hog Fuel	2.7	0	4.2	0	5.7	0
Purchased Electricity	4.5	117	5.0	117	5.4	126
Natural Gas	4.6	228	4.1	204	3.8	189
Oil	9.1	658	4.6	333	3.1	224
Miscellaneous	0.8	18	0.4	9	0.3	7
Total	32.0	1,021	29.1	663	29.4	546

Notes: a CO_2 factors used:

Pulping liquors and hog fuel: no incremental emissions
Purchased Electricity: 1972: 26t/TJ; 1989 & 2010:23.4 t/TJ
Natural Gas: 49.68 t/TJ
Oil: 72.30 t/TJ
Miscellaneous (mainly hydro, some coal): 22.50t/TJ

b Assumes same annual rate of change as occurred between 1972 and 1989.

Numbers may not add due to rounding.

Source: Soulsby (1990), CPPA Energy Monitoring Report, 1989, (Internal Report), The ARA Consulting Group.

Exhibit 4.3: Energy Profile for Pulp and Paper by Province

	Percent Energy Consumption (1989)		
	B.C.	Ontario	Quebec
Coal	0.4	1.7	-
Oil	10.9	3.2	24.0
Natural Gas	10.6 [a]	31.4	11.5
Sub-Total	21.9	36.3	35.5
Hogged Fuel	17.2	9.8	9.7
Pulping Liquor	50.1	34.1	24.3
Sub-Total	67.3	43.9	34.0
Purchased Electricity	9.7	15.1	27.9
Total	***98.9***	***95.3*** [b]	***97.4***

Notes: a Before Vancouver Island natural gas pipeline.
b 3.7% of remaining sources is from self-generated hydraulic power.

Source: Soulsby (1990), CPPA Energy Monitoring Report Year Ended 31 December, 1989, (Internal Report), CPPA.

not preclude further interfuel substitutions. These could include replacing virtually all oil and coal with natural gas, or substituting virtually all fossil fuels with electricity and/or self-generated fuels.[2]

Furthermore, there is no publicly available information to suggest that B.C. mills are significantly more energy efficient than mills in other provinces so that energy conservation measures are as appropriate here as in other jurisdictions. However, because the pulp and paper industry makes extensive use of self-generated fuels with a zero emission factor, energy conservation measures in other sectors where the conservation of fossil fuels is more direct (e.g., transportation) may have a greater impact on CO_2 emission reductions in the provinces than conservation efforts in the pulp and paper industry. On the other hand, the absolute amount of energy consumed by the pulp and paper industry warrants energy conservation initiatives.

In Exhibit 4.4, we have pulled together some numbers from a variety of sources to *suggest* possibilities for CO_2 abatement in the B.C. pulp and paper sector. We emphasize that these figures are purely illustrative as they are scaled up from very location and application-specific data for individual mills. Furthermore, the list is in no way comprehensive.

However, Exhibit 4.4 does suggest that CO_2 abatement opportunities do exist and that further energy conservation, interfuel substitution, and process changes would seem to support reductions in CO_2 emissions in the pulp and paper sector at the same rate as experienced in the past; i.e., reductions in the order of 18% over the next ten years (see Exhibit 4.2). This reduction in CO_2 emissions represents a drop of about 4400 kt per year (based on 1989 CO_2 emissions) which translates into about 5% of total provincial emissions.

As noted above, process changes could also reap significant energy and CO_2 abatement. In particular, a shift towards mechanical pulping (TMP/CTMP) mills and greater recycling could have important implications. Representative gross energy use values for kraft, CTMP and recycling pulp mills are:

Kraft	19 GJ/ADMT	thermal and electric
CTMP	9 GJ/ADMT	electric
Recycle	2 GJ/ADMT	electric.

As indicated, recycling mills use approximately 10% of the energy required by a kraft mill (per ADMT), with CTMP at about 50% of kraft. CTMP and recycle mills use primarily electricity purchased from the main grid as opposed to a combination of electric and thermal which has higher unit CO_2 emissions. Finally, CTMP and recycle mills at the mill level do not generate biomass wastes at the same rates as kraft mills, that then need to be burned or otherwise disposed of. Consequently, the appropriate comparison of emissions from CTMP and recycle

[2] Although the shift to natural gas will continue as access is extended, the provincial energy demand forecasts still project significant consumption of heavy fuel oil through to the year 2010, based largely on the expected softness in oil prices. Opportunities for substituting away from oil are ultimately limited; to secure energy supplies, mills will maintain relatively small oil supplies as back-up.

Exhibit 4.4: Examples of CO_2 Management Measures for Pulp & Paper (Illustrative values only)[a]

			Annual CO_2 Reductions[b]			
		Energy type saved	kt/year	% 1989 Pulp & Paper Emissions	Lifetime CO_2 Reductions[c] (kt)	Cost-effectiveness ($ per tonne CO_2)
1.	Insulating stock chest	Thermal	1	<0.1	9	-85
2.	Reduction of lime kiln heat losses by low emissivity point	Thermal	7	<0.1	22	-340
3.	Recovery & reuse of paper machine white water	Thermal	2	<0.1	25	-1,100
4.	Energy efficient motors	Electric	10	<0.1	50	-50
5.	Variable speed drives	Electric	15	<0.1	70	-175
6.	Energy efficient lighting	Electric	5-20	<0.1	40 to 180	-195 to -205
7.	Heat pinch technology	Thermal	1045	4.0	10,450	-65
8.	State-of-art digesters	Thermal	255	1.1	2550	d
9.	Impulse drying	Thermal/ Electric	170	0.7	1780	d
10.	State-of-art evaporation (MEE & VRE)	Thermal	60	0.3	600	?
11.	Substitute 2000 ADMT from Kraft to recycle mills[e]	Thermal/ Electric	1945	8.2	38,920	f

continued...

Exhibit 4.4: Examples of CO_2 Management Measures for Pulp & Paper (Illustrative values only) cont'd

		Energy type saved	Annual CO_2 Reductions[b] kt/year	% 1989 Pulp & Paper Emissions	Lifetime CO_2 Reductions[c] (kt)	Cost-effectiveness ($ per tonne CO_2)
12.	Substitution to 100% self generated fuels	Fossil fuels, Purchased electricity	3805	16.0	76,115	g
13.	Substitution to natural gas	Fossil fuels	445	1.8	8,940	-40

Notes:
a Sources for measures: Azarniouch (1991), Herzog & Tester (1991), OTA (1991).
b CO_2 factors are: electricity 15.91t/TJ; thermal 12.81t/TJ; electricity/thermal 13.43 t/TJ
Assumes average fuel blend saved; could underestimate CO_2 abatement potential to the extent that, at the margin, purchased energy (likely fossil fuels) would be reduced first.
c Emission reductions not additive across measures.
d Depends on capital costs: likely cost-effective for new installations and/or as replacements.
e Energy-related emission reductions only; collection and transportation of waste paper may affect the overall reductions if significantly more energy is needed than for the harvesting of virgin pulp.
f Depends on capital costs, raw material costs and market conditions. Comprehensive analyses are outside the scope of study. However, may be cost-effective in some conditions.
g Depends on capital costs and availability of raw material. Could be cost-effective in new installations.

pulp mills to kraft pulp mills must take into account emissions from self-generated fuels. The implications for CO_2 emissions are approximated as:

	CO_2 emissions kg/ADMT[3]	Difference with Kraft kg/ADMT	Difference with Kraft as% Kraft
Kraft	995	n.a.	n.a.
CTMP	<110	-885	<11
Recycle	22	-973	2

As shown, energy-related CO_2 emissions from recycling plants are just 2% of the kraft emissions. This figure does not include savings in forest harvest (and, hence storage of carbon) or energy consumed in harvesting; on the other hand, it also excludes increased energy use for collection and transportation of waste paper. Based on energy savings at the mills alone (and ignoring for the moment differences in product properties and end uses), the figures above suggest that a shift of 2000 ADMT kraft production to recycled products through, for example, rapid growth of this segment of the industry, could reduce emissions by about 2000 kt, or 8% of the industry's total CO_2 emissions.

Although the energy and CO_2 emission reductions associated with CTMP and recycle mills are impressive, the treatment of such significant process changes must take into account the inherent differences in the end products and implications on a "cradle-to-grave" basis. For example, CTMP does use less energy, but, most of that energy is electricity purchased from the grid, so a move to CTMP may compromise other energy self-sufficiency goals and put pressure on B.C. Hydro capacity.[4]

4.4 Cost-Effectiveness

Exhibit 4.4 also indicates the cost-effectiveness of the illustrative measures. Again, we warn that most of the values are based on a single installation cases and are not necessarily applicable to or representative of the industry as a whole. However, the figures do suggest that there are a range of measures that could generate overall savings (i.e., the cost-effectiveness ratio is negative). This result is not surprising as some of the measures included in Exhibit 4.4

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[3] CO_2 factors used are:

Kraft 52.33 t/TJ (weighted average of all mills in B.C., all energy sources, with a zero factor for 40% of self-generated fuels) A zero factor for self-generated fuels is applied to only a portion -- instead of all -- of kraft use of these fuels. Assuming that 60% of virgin pulp is replaced with recycled material, we have given a zero factor to only 40% of pulping liquors.

CTMP 12.32 t/TJ (average for purchased electricity from the main grid)

Recycle 12.32 t/TJ (average for purchased electricity from the main grid)

[4] A significant shift to CTMP in B.C. would exceed current electricity resources and would likely require a new and large hydroelectric dam to meet increased demand. Although hydroelectricity is considered a relatively CO_2-benign source of energy (see Section 7), the carbon cycle of hydro dams is not yet fully understood.

a range of measures that could generate overall savings (i.e., the cost-effectiveness ratio is negative). This result is not surprising as some of the measures included in Exhibit 4.4 represent projects that are already in place and that presumably wouldn't have been undertaken unless the payback was attractive.

For other measures, we expect that overall savings could be generated, but were unable to find reliable cost information. The net costs of yet other measures depend on the specific application (e.g., new/retrofit, prices for recycled fibre). In these cases, we can surmise that net savings could be generated in some instances, but not as a general rule.

In the spirit of the discussion in Section 4.2., the estimates of cost-effectiveness in Exhibit 4.4 should be interpreted with care. Specifically, the figures do not allow us to compare one measure with another. Rather, the numbers suggest that at least some of the CO_2 reduction measures that would support an 18% decline in emissions over the years 1989 to 2000 could generate net savings for the mill.

4.5 Summary

The main conclusions drawn from the above analysis are:

- The pulp and paper industry is a large source of CO_2 emissions. However, these emissions are primarily from the combustion of self-generated fuels (i.e., hog fuel and pulping liquor) that are waste products of the forest industry processes. Reducing the consumption of these fuels does not, therefore, result in any net reductions in provincial CO_2 emissions ***unless*** measures are coupled with efforts to reduce the amount of waste generated (e.g., CTMP, recycling), or to use the waste in a manner which stores carbon over the long term (i.e., in durable products).

- Because of the fuel mix, CO_2 emission reductions from energy efficiency improvements and some process changes will likely be lower (on a per unit energy consumed basis) than in other sectors. For example, energy efficiency improvements in the pulp and paper industry will generate CO_2 savings of about 13 t/TJ compared with transportation fuel efficiencies that could generate savings of about 67.98 t/TJ.[5]

  However, the sheer magnitude of energy consumption in the pulp and paper industry suggests that energy efficiencies could yield significant CO_2 reductions on an absolute basis. (For example, a 10% reduction in energy consumption in the pulp and paper sector would result in a reduction in CO_2 emissions of about 2300 kt. A reduction of this magnitude would require reductions in energy use in the order of 20% in the transportation sector and 40% in the residential/agricultural sector). Energy

[5] The value 13 t/TJ represents average CO_2 emissions weighted by fuel types (self-generated fuels given a zero factor). The value of 67.98 t/TJ for the transportation sector is the CO_2 emission factor for motor gasoline.

efficiency measures are not detailed in this report because data on the multitude of options is either not available or cannot reliably be manipulated. However, it does seem reasonable that shifts in the energy use pattern experienced over the last two decades could be continued, resulting in an 18% drop in CO_2 emissions over the next decade.

- Process changes offer opportunities for significant CO_2 reductions because they could reduce the volume of biomass/liquor waste that is generated and burned. Both recycling and CTMP reduce the amount of energy required in processing as well as the volume of wood residue (including black liquor). However, the appropriateness of such shifts in processes must take into account a multitude of other factors and should assess the carbon fates of different process products from harvest through to final disposal, an exercise which is beyond the scope of this study.

- Costs associated with specific measures depend heavily on location- and application-specific factors. It is, however, reasonable to believe that many cost-saving energy efficiency measures are available. More problematic is the cost-effectiveness of shifts in process or fuel type. For example, shifts of sectoral production from kraft to recycled or CTMP are only likely to be considered in new investment decisions and by taking into account product differences. Similarly, conversion to 100% self-generated fuels would likely only be commercially feasible when it can be incorporated into a new mill design.

5.0 Road Transportation

5.1 CO_2 Emissions

Mobile combustion is the third largest contributor of CO_2 emissions in B.C., accounting for 21% of the provincial total. About 63% of mobile combustion sources is attributed to road transportation, representing 14% of provincial emissions. With vehicles miles travelled and number of vehicles on an increase, it is likely that vehicle emissions will also rise, as reflected in the projections for CO_2 emissions. Specifically, emissions from road transportation are expected to rise 17% by 2010, increasing their share to 15% of provincial emissions.

The B.H. Levelton (1990) report divided road vehicles into eight categories by vehicle type and fuel type. The categories are as follows:

- Light Duty Gasoline Vehicles (LDGV)
- Light Duty Gasoline Powered Trucks 1 (LDGT1)
- Light Duty Gasoline Powered Trucks 2 (LDGT2)
- Heavy Duty Gasoline Powered Vehicles (HDGV)
- Light Duty Diesel Powered Vehicles (LDDV)
- Light Duty Diesel Powered Trucks (LDDT)
- Heavy Duty Diesel Powered Vehicles (HDDV)
- Motorcycles (MC)

Unfortunately, the literature on measures to reduce CO_2 emissions in the transportation sector, while vast, does not adequately apply measures to these specific vehicle types. Rather measures are distinguished for either transportation as a whole, commercial versus private transportation use, or are discussed anecdotally. In the list of potential measures developed for this study, the private/commercial distinction has been adopted, with LDGVs, LDDVs and MCs (abbreviations explained above) falling under private use and all other vehicle types falling under commercial use. Natural gas, propane and off-road vehicles are treated separately.

Emissions of CO_2 in the road transportation sector are estimated for 1989 as:

Source	Fuel type	k tonnes CO_2 (1989)	% provincial total
Private	Gasoline	5,655	6.1
	Diesel	815	0.9
Commercial	Gasoline	3,130	3.4
	Diesel	2,320	2.5
Other	Natural gas	45	0.1
	Propane	305	0.3
	Off road	360	0.4
Total		***12,640***	***13.6***

(Numbers may not add due to rounding)
Source: Appendix C

5.2 Management Measures

Because road transportation accounts for such a large proportion of CO_2 emissions in all jurisdictions, it is well covered in the literature on CO_2 abatement policies. For example, Lashof and Tirpak (1990) and OTA (1991) have detailed discussions of potential measures and Transport Canada (1989) has an extensive compilation of various industry and association responses to CO_2 reduction possibilities in the transportation sector.

The two most comprehensive studies *that provide estimates of costs and savings* for the widest range of measures are Alberta Energy (1991) and The DPA Group Inc. (1989). Because the two studies had common measures, and to avoid double-counting, the options examined in this study are based largely on the Alberta study. The data in the Alberta study have, however, been modified based on up-dated information references (as noted) and the specific characteristics of the B.C. road transportation sector.

Management measures focus primarily on energy efficiency and interfuel substitution opportunities but can be divided into four general categories: (i) Vehicle energy efficiency; (ii) Traffic management; (iii) Trip reduction; and (iv) Interfuel substitution.

5.2.1 Vehicle Energy Efficiency

Three distinct measures are included in the vehicle energy efficiency category: (i) vehicle fuel efficiency;(ii) vehicle maintenance; and (iii) vehicle retrofits.

Vehicle fuel efficiency improvements in vehicle design is the most common energy efficiency measure in this category. Automobile manufacturers, pushed by the oil shocks, U.S. CAFE regulations, and consumer preference for smaller, more fuel efficient cars, have greatly improved the fuel economy of light duty vehicles. In Canada, for example, actual fuel efficiency for *new* passenger cars has improved from 11.5 *l*/100 km in 1978 to 8.2 *l*/100 km in 1985, or almost 30% (Lashof and Tirpak, 1990).

Although some believe that the internal combustion engine is facing "inherent performance limits" (Sobey, 1990), much of the literature indicates that further improvements in fuel efficiency can be generated from weight reductions, improvements to aerodynamics and rolling, and engine and drive train modifications (e.g., combustion chamber and cylinders, diesel fuel injection systems). For example, the International Energy Agency predicts a further improvement in Canada to 6.8 litres/100 km by 1995 (IEA, 1987).[1] VHB Research & Consulting (1991) reviewed a range of studies predicting improvements in fuel efficiency, the

[1] Several prototype vehicles have been produced that can reduce city fuel consumption to 89 mpg or 1.6 l/100 km (EPA, 1990); however, these prototypes are strictly demonstration vehicles and do not necessarily represent designs that would meet the requirements of mass production technology or consumer demands for comfort, safety, power, emissions, etc. These prototype fuel efficiencies do not, therefore, represent realistic benchmarks for expected improvements in average fleet fuel economy.

results of which are reproduced in Exhibit 5.1. (Note: The last row in Exhibit 5.1 provides the results of a regression analysis of the literature estimates.)

For the purposes of this analysis, we have assumed that fuel efficiency improvements of 35% (from 10.4 *l*/100 km to 6.8 *l*/100 km) in half the fleet are attainable over the next decade. This represents an improvement in average fleet efficiency of about 17%, an assumption that is consistent with the VHB "medium stringency" scenario and is conservative compared to IEA and other predictions (Cheng, 1988 and Energy and Environmental Analysis, 1988 as reported in OTA 1991, pg.158; and The DPA Group, 1989).

Vehicle maintenance includes a variety of maintenance measures such as correcting timing, tire pressure, air/fuel mixtures, choke conditions, idling rpm, wheel alignment, etc. The most common mechanism for maintenance measures is a compulsory vehicle inspection and maintenance (I/M) program. Like many other jurisdictions (e.g., Portland. Seattle, California, and many European countries), the GVRD is introducing an I/M program to control automotive emissions. The program has a specific focus on NO_x, CO, and HC emissions, but will concomitantly improve fuel efficiency and, therefore, CO_2 emissions.

In this study we examine I/M benefits in the order of 5% fuel savings (4% in the commercial sector). These values are conservative relative to other studies, as shown below:

Reference Study	Fuel Efficiency Gains
OTA (1991)	5% (trucks)
VHB Research and Consulting (1991)	5%
Alberta Energy (1990)	8%
The DPA Group (1989)	15%[2]

The I/M program represents an important component of the road transportation management measures as it addresses in-use (vs. new) vehicles and provides safeguards against deterioration of new vehicle fuel efficiency potential discussed in the previous measure.

Vehicle retrofits are defined as "vehicle aftermarket add-on devices or products" that reduce fuel consumption (Alberta Energy, 1990). Specific components of vehicle retrofits include: conversion to radials, wide-based tires instead of duals, oil grade, temperature-controlled fan, truck box covers, etc. Many of these measures have the potential -- *individually* -- to improve fuel economy by 3-5% when applied.

Overall, however, some of these retrofits have already been done and their application/attractiveness will not apply to all segments of the road transportation sector. For

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[2] Includes modifications to driving habits which are treated separately in this study (see "Driver education" below). Although the 5% value may be conservative, a doubling of fuel efficiency to 10% savings does not alter the final categorization of the measure (see Section 9).

Exhibit 5.1: Comparison of Future Fuel Consumption Estimates (l/100 km)

Description and Source[a] of Estimate	Year of Estimate 1990	1995	2000	2005
1. Fleet average (MENY Energy Demand Model, 1989)[b]	10.76	10.54	9.97	9.52
2. New vehicle average (MENY Energy Demand Model, 1989)[b]	10.27	9.50	8.94	8.97
3. Average vehicle < 1,000 kg (Statistics Canada, 1989)[d]	8.80	n.a.[c]	n.a.	n.a.
4. "Best car" on market (Transport Canada, 1989)[e]	5.00	n.a.	n.a.	n.a.
5. Prototype vehicles (Bleviss, 1988)[f]	3.10	n.a.	n.a.	n.a.
6. Linear regression analysis (VHB Research and Consulting, 1991)[g]	7.86	7.28	6.76	6.24

Note:
[a] Full references are provided in the bibliography
[b] Ontario Ministry of Energy (1988)
[c] Not available
[d] Figure is for January to December, 1988
[e] Pontiac Firefly 5-sp, 55/45 urban/highway
[f] Average of seven prototype vehicles.
[g] Linear regression of various literature estimates, excluding high and low values

Source: VHB Research and Consulting (1991)

that reason, we have examined the impact of 1% savings in the private sector and 3% savings in the commercial sector on CO_2 emissions.

An additional method for improving fleet energy efficiency is to replace older cars through a re-purchase or SCRAP program. This offers some potential but raises concerns regarding equity and ability to identify highly polluting vehicles. Specifically, the re-purchase plan could be viewed as discriminatory or "rewarding the worst polluters" unless an appropriate, effective and broadly accepted screening process is designed and implemented.

5.2.2 Traffic Management

This category of road transportation measures focuses on improving fuel economy by managing traffic patterns. Three separate measures are examined: (i) route and traffic planning; (ii) driver training; and (iii) intermodal shifts.

Route and traffic planning consists of a variety of measures to improve urban traffic flow and to reduce stop-and-go patterns. An integral part of route planning measures is to reduce congestion and, therefore, idling time.[3] Specific measures include improved traffic signal systems, widening of intersections, improved street lighting, computerized traffic control systems, bus bays and lanes, improved route identification, trip consolidation, order preplanning, converting unnecessary stop signs to yield signs, reversible lanes and streets, better traffic advisory systems, etc.

Estimating the potential reduction in energy consumption is complicated by the dearth of quantitative analyses for individual measures (Alberta Energy, 1990), generalizations as to the applicability of different specific measures in different urban centres, and defining a *package* of measures. Based on the literature, we examine a 10% decrease in energy consumption that could be generated by a set of route planning and traffic management measures in the private transportation sector and a 15% decrease in the commercial sector both in the Lower Mainland only.[4]

However, we emphasize that these measures, while reducing per vehicle fuel consumption, could have a perverse impact on total energy consumption. Put simply, congestion is one barrier to driving so that improvements in traffic flows (and consequent savings in travel time) could stimulate increased demand for road transportation. If not accompanied by measures to reduce vehicle miles travelled (VMT), route planning and traffic management measures could, overall, increase CO_2 emissions.

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[3] In the Los Angeles area, traffic congestion is expected to reduce average speed from about 35 mph in 1984 to 19 mph in 2010, with a subsequent reduction in average fuel economy of as much as 25% for those vehicles (OTA, 1991).

[4] It is assumed that energy savings are higher in the commercial than private sector because many more route planning measures such as trip consolidation, order preplanning, load optimization over all vehicles, and optimizing the number and location of terminals apply strictly to commercial vehicles.

Driver training regarding the effects and benefits of moderate acceleration, turning off motors when stationary, less reliance on brakes, etc. can generate energy efficiency gains. An Alberta study estimated potential fuel savings for general public drivers at 10% (Transportation Energy Audit Database as reported in Alberta Energy, 1990). However, estimates used in this study are a more modest 3% and 6% in the private and commercial sectors, respectively. Driver training is likely more effective for commercial vehicles as potential savings are larger and, therefore, the incentive for commercial fleet operators to offer training greater.

Intermodal shifts refer to a shift in commercial traffic from road to rail. To indicate the type of savings that are technically possible, we examine a shift of 20% of truck traffic with a 75% fuel saving. This assumption does not imply that the shift could be implemented with ease; infrastructure requirements limit the practicality of this measure.

Other studies have also examined the impacts of rail electrification (e.g., The DPA Group, 1989), however it is not included in the set of measures examined in this study for two reasons. First, electrification encounters the same (or more severe) infrastructure problems as a general shift to rail; and second, electrification would only be viable as a national measure.

5.2.3 Trip Reduction Measures

Trip reduction measures include efforts to restrict the number of vehicle trips needed (through land use planning, modifications to work weeks, or telecommuting) and the overall number trips (through a variety of measures).

Land use planning approaches to energy conservation focus on the paradigm: "access by proximity" rather than access by transportation. Two factors determine energy consumption for different land use plans: density and mix. Density refers to the population density; mix refers to the mix of land uses. Most important is the mix of residential and employment destinations, although proximity to shopping, schools, and other facilities affect transportation needs. Land use planning efforts, therefore, are directed towards creating community nodes that place amenities close to demand, as well as intensifying land use.

Density and proximity to destinations have two complementary impacts on energy demand. Proximity clearly reduces the distance that must be travelled to reach any destination. Proximity also encourages alternatives to the automobile. Bicycling and walking are much more viable over short distances, while the feasibility of extensive transit systems (and perhaps consumer acceptability) are enhanced within high density areas.

The role of land use planning is clearly recognized in The City of Vancouver's initial response to the global change challenge. The City's *Clouds of Change* report (City of Vancouver, 1990) forwards eight recommendations as environmental measures. Specific measures suggested in *Clouds of Change* as well as other documents include:

- residential intensification -- increasing the density of residential areas through, for example, multiple unit residential developments;

- reurbanization -- intensifying use of existing urban lands and structures through infill, renovation of older and abandoned structures, etc;

- hardening the urban fringe -- defining the confines of an urban area/community to prevent urban sprawl through zoning and restrictions on outlying shopping malls;

- changes in zoning laws and principles -- enhancing the integration of multiple land uses (rather than continuing the traditional practise of separating uses) as one method of creating multiple needs communities; and

- developing self-contained communities -- an extension of the previous measure, developing self-contained communities involves decentralizing community services and providing walking/bicycling routes.

Defining potential CO_2 reductions for each of these measures individually is outside the scope of this study. However, some sense of the impact of increased population job density can be drawn from previous studies on the relation between urban density and gasoline use. Exhibit 5.2, Panel a) shows transportation energy implications of alternative urban development patterns. Increasing density and, therefore, proximity can reduce energy consumption significantly, as indicated by the 50% difference in energy use between low density sprawl and high density planned development patterns. These statistics underscore the significant potential of energy-conscious land use and regional planning approaches in managing CO_2 emissions.

Statistics from the GVRD and Vancouver Metropolitan Census Division (Exhibit 5.2, Panel b) reflect a very wide range of population density estimates. Please note that these values are not directly comparable to those in Panel a) because they use land area, not *developed* area as the denominator. (The different bases for calculation can sometimes make a significant difference, as suggested by the very low density value for North Vancouver District compared to the City of North Vancouver.)

Of note in Panel b) is the range of densities across different municipalities within the GVRD. While the City of Vancouver and some other municipalities (e.g., New Westminster, City of North Vancouver, Whiterock) have densities in excess of 25 persons per hectare, some municipalities relatively close to the downtown core (e.g., University Endowment Lands, Coquitlam, West Vancouver) have very low densities. Overall, GVRD has a population density of about 5.4 persons per hectare, based on 1986 Census data. This figure reflects the "bedroom town" structure of the regional district, wherein outlying communities such as Richmond, Surrey, Burnaby, Coquitlam, etc. are economically tied to Vancouver.

Consolidated work week and staggered working hours were first introduced in response to oil shortages and crisis-oriented efforts to conserve energy. For the same energy efficiency reasons, modifications to the standard work week are included in the set of CO_2 management measures. In this study we adopt a 10% energy savings for private urban vehicles only (The DPA Group, 1989).

Exhibit 5.2: Transportation-Land Use Relationship

Panel A: Transportation Energy Implications of Alternative Development Patterns

Community Development Pattern	Population density[a] (persons/ha)	Gasoline use (relative to low density sprawl)
Low density sprawl	17.8	100%
Low density planned	19.8	81%
Planned mix	26.8	63%
Combination mix, 50% Planned Urban Development, 50% sprawl	28.0	75%
Sprawl mix	29.3	90%
High density planned	37.5	50%

Notes: a Population per hectare of development area.
Source: VHB Research & Consulting (1991) based on RERC (1974).

Panel B: Population Density for GVRD, 1986

	Population density[a] (persons/ha)
Burnaby	16.4
Coquitlam	1.9
Delta	4.7
Langley City	16.3
Langley Township	1.8
New Westminster	26.0
North Vancouver (City)	33.1
North Vancouver (District)	4.2
Port Coquitlam	10.8
Port Moody	11.5
Richmond	8.7
Surrey	6.0
UEL	2.5
Vancouver	**38.2**
West Vancouver	4.1
Whiterock	28.5
GVRD	**5.4**
Pitt Meadows	1.6
Maple Ridge	1.4
Vancouver CMA	**5.0**

Notes: a Population per hectare of land area.
Source: Statistics Canada Catalogue, pp 94-119.

Telecommuting could have similar impacts as the consolidated work week by reducing the number of days employees have to commute into work. Telecommuting is not appropriate for many jobs (e.g., manufacturing) but could assist in reducing the number of trips into the city core by clerical workers and professionals. For example, working from home one day per week could reduce an individual's number of commute trips by 20% annually. For this study, we have included telecommuting under the 10% savings estimated for consolidated work week/staggered working hours because of the difficulty in assessing the proportion of commuters whose jobs are amenable to telecommuting.

Trip reduction measures have received considerable attention in California where urban air quality concerns are motivating stringent emissions and vehicle use regulations. Indeed, the South Coast Air Quality Management District (SCAQMD) introduced a comprehensive trip reduction program -- Regulation XV -- in 1989. A number of other municipalities and areas have also introduced trip reduction ordinances (e.g., Bellevue, Washington; Minnetonka, Minnesota; North Brunswick, New Jersey) but California is most active in this area and the SCAQMD's plan is the first comprehensive regional regulatory program of its kind (Lopez-Aqueres et.al., 1991).

The objectives of trip reduction programs are usually expressed in terms of increasing Average Vehicle Ridership (AVR). The SCAQMD plan calls for an increase in AVR from the regional average of 1.1 people to 1.5 on commuting trips. Anticipated benefits are significant and include: 750,000 fewer trips per day totalling about 14.8 million vehicle miles per day and reductions in CO, ROG and NO_x emissions of 127 to 274 tons per day.[5] In addition, it is expected that both employers and employees will realize cost savings from reduced parking expenditures as well as reduced fuel and car maintenance costs.

Regulation XV is structured as follows. All employers with 100 or more employees must develop a corporate trip reduction plan to bring their current AVR up to the target AVR for their area.[6] The plans embody a considerable amount of data and analysis of commuting patterns, worksite characteristics and transportation alternatives. The plans also require the employer to clearly set out specific incentives and programs that will be used to reach the target AVR. The plans are then approved by SCAQMD staff and monitored annually. Employers must also appoint an "Employee Transportation Coordinator" (ETC) to prepare, implement and monitor the trip reduction plan.[7]

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[5] The primary rationale behind Regulation XV is to reduce pollutants related to ground-level ozone and toxics. However, any measure that results in reduction in vehicle miles travelled and fuel consumption will also clearly reduce carbon dioxide emissions.

[6] While the target AVR for the Regulation as a whole is 1.5 people, individual targets are set for different areas.

[7] An excellent summary of the administrative features of Regulation XV is presented in Lopez-Aqueres et.el. (1991).

The basic theme behind trip reduction plans is to change the incentives that affect transportation mode choices of employees. The primary tools for changing behaviour can be divided into three main groups, each of which is described below. In general, a package of incentives (rather than a single initiative) is required to increase AVR and in many instances benefits from area or region-wide initiatives.

Parking policy: Parking policy is one of the central factors in reducing vehicle trips. Ulberg (1991) shows that implicit parking subsidies in the United States could exceed $30 billion per year. Ulberg also argues that, apart from personal factors such as convenience and independence, decisions to drive are generally based on marginal costs of driving comprised mainly of fuel costs. (Costs related to general maintenance and wear and tear on a vehicle are not generally taken into account in mode choices.) Yet parking costs, if not subsidized, could overwhelm fuel costs by a factor of 30. Several studies have concluded that higher parking costs definitely discourage driving alone.[8] In downtown Vancouver, approximately 50% of parking is employer-subsidized.

Parking pricing can take a number of forms. Tax modifications could include eliminating parking expenses as a deductible business expense (which would further increase the cost to the employer of providing parking) or including parking as a taxable benefit to the employee. Parking policies could also include:

- parking subsidies to ridesharers;
- preferential parking (e.g., location) to ridesharers;
- higher parking fees or reduction in parking subsidies for single-occupancy vehicles; and/or
- employee cash allowances in lieu of parking.

On the supply side, parking can be restricted through urban planning measures such as caps on the number of parking places available in a certain area, tax incentives to developers to minimize parking places, adjusting development permits to specify maximum rather than minimum parking, and/or reduced minimum parking requirements in return for provision of bicycle facilities (e.g., bike racks, showers and lockers) or designated car/vanpool spaces.

The City of Vancouver has had a parking policy for new developments in place for a number of years. In 1986, the maximum number of parking spaces was set at 1 space per 4 employees, with the intention of gradually tightening parking supply to encourage transit use.

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[8] See for example: Urban Mass Transportation Administration (UMTA) (1989), *An Assessment of Travel Demand Approaches at Suburban Activity Centers (First Report).* U.S. Department of Transportation, Office of Technical Assistance and Safety; Kuzmyak, J.R. and E. Scheffler (1990), *Evaluation of Travel Demand Management to Relieve Congestion.* Washington, D.C.:FHWA-SA-90-005; Pickrell, D.H. and D.C. Shoup (1980), "Employer Subsidized Parking and Work Trip Mode Trip" in *Transportation Research Record No. 786.* Commonly cited is a decision by the Canadian federal government in the early 1980's to require employees to pay parking prices equal to 70% of the market rates. The decision led to a 23% decrease in the number of people driving alone.

The contribution of parking policies to CO_2 abatement in B.C. is considered in conjunction with rideshare measures discussed below.

Ridesharing programs: Efforts to reduce trips by directly increasing AVR include creation of carpooling, vanpooling and buspooling programs. Supporting initiatives can significantly increase the success of such programs. These include:

- full or partial subsidies (e.g., cash allowances) to those who rideshare;
- ride matching services; and
- guaranteed rides home.

Promotion and marketing of ridesharing in the workplace can also enhance effectiveness of rideshare programs as does visible senior management support. Finally, the SCAQMP has found that designation of an Employee Transportation Coordinator who can assist in developing carpools and matching rides leads to higher carpool formation and effectiveness (Lopez-Aqueres et.al., 1991).

The potential to reduce carbon dioxide emissions through rideshare programs and parking policy is included in this study as a 15% decrease in urban traffic. This corresponds to an increase in urban traffic (private transportation) AVR from 1.3 to 1.5 people.[9]

Public transportation: The measure labelled "*public transportation*" encompasses an increase in the use of public transportation, especially during peak traffic hours. Urban buses can reduce energy consumption per passenger-kilometre by up to 90%, although the impact on emissions will also depend on the type of transit service provided. In the GVRD and Victoria, increased transit use could be met by either an increase in diesel or electric service. Electric service, through increased use of trolley cars or extension of the Light Rapid Transit (LRT) system, would have a more significant effect on carbon dioxide emissions but raises questions regarding electricity supply options (see Section 8).

Various studies have examined the impact of increased transit use. The DPA Group (1989) assumes a 40% decrease in energy use in private urban vehicle energy consumption but does not relate this figure to an increase in transit use; Alberta Energy (1990) assume a 2.5% increase in transit ridership per year (totalling a 47% increase over the next 15 years); and notwithstanding a decline in ridership in 1990, VHB Research and Consulting (1991) suggest

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[9] The reduction from 1.3 to 1.5 is somewhat lower than either the City of Vancouver's Clouds of Change goal or the targeted increase in the SCAQMD's regulation. We have adopted this more conservative target because a number of the measures used in the documents for both initiatives -- increased transit use and consolidated work week/staggered hours/telecommuting -- are treated separately in our management measures. The move to 1.5, then, falls on the parking and rideshare measures only.

that a "realistic" scenario would increase transit use in the Greater Toronto Area by almost 70% by the year 2005.[10]

In this study, we examine a 50% increase in transit's share of GVRD passenger-trips which implies a 6% decrease in passenger-trips by car. Taking into account average occupancy, differential fuel consumption, and urban vehicle transportation use (as a percent of provincial use) the 50% increase in transit use reduces provincial energy use in the private transportation sector by about 3%. (Detailed calculations are provided in Appendix A).

Local Initiatives: Both the City of Vancouver and the GVRD have explored some of the measures outlined above. In the City's *Clouds of Change* report, seven recommendations concerning transportation planning and traffic management were forwarded. The recommendations included development of a trip reduction plan (to increase AVR from 1.3 to 1.75) based on the California model, including parking and telecommuting policies. The report also suggested that a system of road pricing and transit improvement be examined, and that bicycle transportation be encouraged. Some of the studies recommended in *Clouds of Change* have been drafted and were submitted to City Council in February, 1992.

5.2.4 Interfuel Substitution

Alternative fuels have been the subject of considerable research and debate. California has introduced a Low-Emission Vehicle and Clean Fuels Program as part of their air pollution strategy, setting targets for in-use clean fuel vehicles for the mid 1990's and early 2000's. Although the California (and many other) clean fuel programs are motivated by emissions of CO and ozone precursors, alternative fuels have also been examined as a CO_2 abatement measure.

Possible alternatives to gasoline include:

- diesel
- compressed natural gas (CNG)
- propane
- methanol
- ethanol
- electricity
- hydrogen.

[10] The current (24-hour) transit share in the Greater Toronto Area is about 18% (VHB Research and Consulting, 1991) compared with a 10% share in the GVRD (TransVision Consultants, 1990).

Exhibit 5.3 outlines most of these fuels and Exhibit 5.4 indicates their CO_2 content on a life-cycle basis.[11] The emission factors for alternative fuels should be considered with caution as they represent current "best guess averages" drawn from a large range of reported figures (L. Vancea, EMR, pers.comm.). The averages also abstract from the specific technology used. For example, vehicles designed and maintained for a given alternative fuel could yield more pronounced improvements in emission reductions than gasoline vehicles that have been converted to alternative fuels or modified to dual-fuel systems. The factors, therefore, are indicative only and subject to considerably more research and practical trials.

Hydrogen is the least developed of the alternatives and will not likely emerge as a feasible transportation fuel for at least 50 years (L. Vancea, EMR, pers.comm.). Consequently, it falls outside the timeframe used for this study and is not included in the list of potential management measures, except as a future technology.

As indicated in the exhibits, electricity is associated with very low levels of CO_2 (because of the dominance of hydroelectricity in the generation mix). Research on electric vehicles is progressing but driving range is still limited by the battery; specifically, the amount of power the battery can provide, considerable recharging time and infrastructure requirements. In this study, we categorize electric vehicles as an unproven technology, although Californian regulations have set a target for "zero-emission vehicles" (ZEV's) such as electricity to account for 2% of annual car sales by 1998 and 10% by the year 2003 (Mader, 1991).

This is an optimistic scenario, but there is some reason to believe that electric vehicles may undergo substantial improvements within the next 20 years. While few are now commercially available, the "big three" U.S. automakers recently announced a $100 million battery development program and there are rumours that other manufacturers (e.g., in Japan) are also embarking on major research programs.

Ethanol and methanol are alcohol fuels. As indicated in Exhibit 5.4, ethanol (if produced from wood) could offer significant CO_2 abatement opportunities but corrodes metal and destroys plastics. Ethanol is also considerably more expensive than traditional fuels: currently, ethanol is roughly twice the pre-tax cost of gasoline.

Methanol is also usually blended with gasoline and has been used in Canada on a trial basis to fuel intercity buses. Methanol has technical problems similar to ethanol, however, methanol also emits formaldehyde, a known carcinogen, and gets lower mileage. As indicated in Exhibit 5.4, methanol CO_2 emissions are only marginally (2%) lower than gasoline. Neither methanol nor

[11] The life-cycle basis is critical in evaluating alternative fuels. If, for example, fossil fuels are used to generate electricity or to produce the alternative fuel, emissions on a "cradle-to-grave" basis could exceed that for traditional motor gasoline (Paaswell, 1990).

Exhibit 5.3: Possible Alternative Fuels

FUEL	ADVANTAGES	DISADVANTAGES
ELECTRICITY	• Potential for negligible vehicle emissions, assuming same mix of electric power as currently exists in B.C. • Can recharge at night when power demand is low	• Current technology is limited • Higher vehicle cost; lower vehicle range, performance • Less convenient refuelling
ETHANOL (e.g., E95)	• Excellent automotive fuel • Very low emissions of ozone-forming hydrocarbons and toxics • Made from renewable sources	• High fuel cost • Somewhat lower vehicle range
METHANOL (e.g., M85)	• Excellent automotive fuel • Very low emissions of ozone-forming hydrocarbons and toxics • Can be made from a variety of feedstocks, including renewables	• Somewhat lower vehicle range
NATURAL GAS	• Low emissions of ozone-forming hydrocarbons, toxics, and carbon monoxide? • Can be made from a variety of feedstocks, including renewables • Excellent fuel, especially for fleet vehicles	• Higher vehicle cost • Much lower vehicle range • Less convenient refuelling
PROPANE	• Cheaper than gasoline today • Somewhat lower emissions of ozone-forming hydrocarbons and toxics? • Excellent fuel, especially for fleet vehicles	• Cost will rise with demand

Source: Adapted from U.S. EPA (November, 1990), *Clean Fuels: An Overview*. Information Sheets.

Exhibit 5.4: CO_2 Emission Factors for Alternative Fuels Relative to Gasoline

FUEL	INDEX[a]
Gasoline	100
Methanol (from natural gas)	98
Diesel	89
Propane	85
CNG	84
Ethanol (from wood)	35
Electricity[b]	18

Notes: [a] Based on vehicle conversions. Life-cycle basis, including consideration of relative fuel efficiencies.

[b] Assumes share of hydropower remains at current levels in British Columbia.

Source: L. Vancea, EMR, pers. comm.

ethanol are included in the list of measures for this study because of marginal abatement potential (methanol) and prohibitive costs (ethanol).[12]

In B.C., more than 50,000 vehicles currently operate on natural gas and propane. Further conversions are included in the list of measures because economic and technical viability have been demonstrated and both offer abatement potential of about 15% over gasoline.

Finally, diesel CO_2 emissions are lower than gasoline on a life-cycle basis (mainly because of greater fuel efficiency) and could generate reductions in CO_2 emissions. Further conversion to diesel is examined.

5.3 Abatement Potential

The management measures for road transportation are listed in Exhibit 5.5, with estimates of annual and lifetime CO_2 reductions. As shown, some measures offer opportunities to substantially reduce CO_2 emissions. In the following discussion, we have grouped private and commercial results for the same measures. (For example, route and traffic planning measures would be implemented without differentiating between commercial and private traffic.)

From the perspective of abatement potential, one measure stands out: vehicle fuel efficiency. This measure generates emission reductions in excess of 2000 kt per year (private and commercial vehicles), or about 16% of the sector's total emissions. A number of measures generate emission reductions in the range of 450 to 1,000 kt per year, including:

- route and traffic planning
- vehicle maintenance
- driver training
- increased use of public transportation
- trip reduction measures
- intermodal shift

Also included in this block of measures are fuel conversions. As indicated in Exhibit 5.5, reductions are greatest for conversion to natural gas (about 955 kt/yr), followed by propane (895 kt/yr), and lastly diesel (655 kt/yr). These differences directly reflect the carbon content of each fuel: relative to motor gasoline (i.e., gasoline = 100), natural gas has a carbon content of 84 compared with 85 and 89 for propane and diesel, respectively. These emission factors are on a "cradle-to-grave" basis and include differing fuel efficiencies among the fuels. As a point of reference, conversion of 50% of the private vehicle fleet to electricity would reduce emissions by 2315 kt per year.

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[12] Methanol and ethanol fuels can contain varying mixes of methanol and gases. Further study may refine the suitability of specific fuels as potential CO_2 management measures, but that lies outside the scope of this study.

Exhibit 5.5: Abatement Potential & Cost-Effectiveness of Management Measures for Road Transportation

	Private Vehicles	Life of Measure	Annual CO_2 Reductions kt	Annual CO_2 Reductions % sector total	Lifetime CO_2 Reductions kt	PV Costs ($ million)	Cost-Effectiveness ($/t)
1.	Vehicle fuel efficiency	10	1,080	8.5	10,810	-455	-42
2.	Vehicle maintenance	2	320	2.5	645	-45	-14
3.	Vehicle retrofits	10	65	0.5	645	290	445
4.	Route and traffic planning	20	385	3	7,740	-635	-82
5.	Driver training	50	195	1.5	9,675	-280	-29
6.	Staggered work hours/consolidated wk week	20	115	0.9	2,340	-190	-82
7.	Trip reduction measures	20	580	4.6	11,600	-954	-82[a]
8.	Public transportation	25	485[c]	3.8	12,185	-105	-8[b]
9.	Fuel Conversion[e]						
	.1 MOG to natural gas[d]	10	455	3.6	4,530	-805	-178
	.2 MOG to propane[d]	10	425	3.3	4,245	-1550	-365
	.3 MOG to diesel	10	310	2.5	3,115	634	203
	Commercial Vehicles						
10.	Vehicle fuel efficiency	10	925	7.3	9,265	-895	-103
11.	Vehicle maintenance	1	215	1.7	215	-15	-65
12.	Vehicle retrofits						
	.1 Diesel	10	60	0.5	595	-55	-92
	.2 Other	10	100	0.8	1,015	40	39
13.	Route and traffic planning	20	375	3.0	7,525	-590	-78
14.	Driver training	40	320	2.5	12,920	-500	-39
15.	Intermodal shift	25	785	6.2	19,625	?	?
16.	Fuel conversion						
	.1 MOG to natural gas	10	500	4.0	5,010	-1645	-328
	.2 MOG to propane	10	470	3.7	4,695	-2455	-522
	.3 MOG to diesel	10	345	2.7	3,445	-610	-[illegible]8

Notes to Exhibit 5.5

See Section 5.2 and Appendix A (Section C) for assumptions.

a Excludes additional savings from parking charges, wear and tear on vehicles and associated infrastructure costs.

b Excludes additional savings from parking charges, wear and tear on vehicles and associated infrastructure costs; excludes transit fares but includes cost of additional transit vehicles.

c Assumes conversion of 50% of gasoline fleet.

d Excludes capital/infrastructure costs except as covered by fuel price.

e Reductions in emissions underestimated because assume private vehicles are replaced by 100% diesel rather than a mix of diesel/electric transit vehicles.

We must emphasize that the CO_2 savings from these measures are *not* additive. For example, the public transportation measure assumes extensive switching from cars to buses or LRT. To the extent that this measure is implemented, savings from driver training, vehicle maintenance, staggered work hours and other fuel efficiency measures will be lower.

However, some measures can be combined. For example, a package of fuel efficiency measures could include:

- driver training -- commercial and private
- staggered work hours -- private
- vehicle maintenance -- commercial and private
- trip reduction measures -- private.

The sum of CO_2 reductions across these measures, pulled from Exhibit 5.5, is 1,745 kt per year. However, this figure overstates actual CO_2 savings because the measures are not applied sequentially. A more conservative value would be 1,575 kt per year, or about 12% of the sector total. By comparison, conversion to natural gas of both private and commercial vehicles could yield reductions in the order of 955 kt per year.

5.4 Cost-Effectiveness

Exhibit 5.5 also records the cost-effectiveness value calculated for each measure. As shown, many of the measures can generate reductions in CO_2 either at some savings or at no cost. This result is consistent with other studies, although there are differences in the specific measures that yield savings and the magnitude of those savings.

In this study, most measures yield savings. For both private and commercial vehicles, conversions from motor gasoline to either natural gas or propane generate the greatest savings -- in excess of $170 per tonne CO_2 reduced. Savings are greater for propane conversions because propane has the largest price differential with gasoline and, therefore, generates the biggest savings.[13] Conversion to diesel differs for private and commercial vehicles. Specifically, diesel conversions could be cost-effective for commercial vehicles but not for private vehicles. The difference can be explained by much higher levels of fuel use per vehicle in the commercial sector. In commercial vehicles, then, the per vehicle conversion cost is spread out over much higher fuel use. In the private sector, the small price differential between gas and diesel coupled with lower per vehicle consumption do not cover conversion costs. Diesel conversion for private vehicles, therefore, is not cost-effective. The difference in fuel consumption may also explain why vehicle retrofits are cost-effective for commercial diesel vehicles but no other vehicle types.

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[13] The savings from conversions depend, in part, on different tax structures for the various fuels. Although not an issue in determining the *commercial* attractiveness of these measures, tax structures can affect the relative importance of conversion from a *social* perspective. Tax structures and their impacts are discussed in Section 9.2 and Appendix E.

Other cost-effective measures (i.e., those that generate savings per tonne CO_2 removed) are:

Savings in Excess of $40/t	Savings less than $40/t
• route and traffic planning	• driving training
• vehicle fuel efficiency	• vehicle maintenance
• staggered work hours	• public transportation
• trip reduction	

Finally, we have included intermodal shifts as a costly measure because infrastructure costs, which we were not able to calculate within the scope of this study, could be significant.

5.5 Summary

The main conclusions that can be drawn from the above analysis are:

- There are a variety of currently available technologies and measures that could potentially reduce CO_2 emissions in the road transportation sector at no cost or, indeed, at significant savings.

- The most promising single measure is vehicle fuel efficiency which is cost-effective (savings in excess of $40 per tonne CO_2 reduced) and generates one of the greatest emission reductions just over 2,000 kt per year or about 16% of sector emissions.

- Conversion of vehicles away from (high carbon) gasoline to natural gas or propane is also promising. Although conversion to propane generates the greatest savings ($365 - $520 per tonne CO_2), conversion to natural gas generates the greatest reductions in CO_2 (955 kt per year compared with 895 kt per year for propane conversions). The two indicators raise a trade-off between the two measures -- to maximize CO_2 reductions (i.e., focus on natural gas) or to reduce CO_2 emissions at least cost (i.e., focus on propane).

- A mix of fuel efficiency measures can also yield significant reductions with attendant savings. Specifically, a combination of driver training, staggered work hours, vehicle maintenance and trip reduction measures implemented for both commercial and private vehicles could reduce emissions by roughly 1,575 kt annually at savings of about $15-80 per tonne.

- A number of commonly discussed measures were explored, with interesting results. As discussed in Section 5.2, trip reduction measures through parking policy, rideshare programs and increased use of transit are central components of several urban air management strategies. Emission reductions of 580 kt per year and 485 kt per year for trip reduction and transit measures, respectively, were estimated generating savings of $80 per tonne and about $10 per tonne, respectively.

- There are a number of emerging technologies that may support and enhance the measures listed in Exhibit 5.5. These include ethanol fuels and other new mobile energy sources. Progress on the electric vehicle, especially in the context of California's clean fuels strategy, also shows promise. Electric vehicles could generate savings on a fuel-cost basis and, with just a 10% share of all vehicles, could generate emission reductions comparable to a 50% increase in public transit use.

6.0 Residential/Agricultural Sector

6.1 CO_2 Emissions

In 1989, residential/agricultural CO_2 emissions in British Columbia accounted for about 6% of provincial emissions. In the year 2010, it is expected that residential/agriculture emissions will increase slightly to 7% of provincial emissions. The CO_2 emission profile for the residential/agricultural sector is:

Energy type	k tonnes CO_2 1989	% of provincial total
Natural gas	3890	4.2
Oil	1175	1.3
Fuelwood	680	.7
Electricity	550	.6
Total	**6285**	**6.8**

Residential energy use dominates this CO_2 profile, and offers the greatest opportunities for CO_2 management. The remainder of this chapter will therefore cover residential measures exclusively. While this approach encompasses farm dwellings, it does not address other farm operations.[1]

6.2 Management Measures

Significant abatement in the residential sector will likely require a combination of measures occurring simultaneously. It is also important that any policy options be implemented for not only for the residential sector but for the building sector as a whole (OTA, 1990); otherwise any reduction in the residential sector could be offset by growth in the commercial sector.

Abatement options for the residential sector are divided into housing (i.e., single family dwellings or SFD) and multi-unit dwellings (MUD) and fall into two categories:

- energy efficiency; and
- interfuel substitution.

[1] Furthermore, the impacts of management measures discussed in this chapter are estimated for changes in natural gas, light fuel oil and electricity use only. LPG's, DFO, HFO, coal and coke account for less than 5% of total energy use in this sector and their omission is not serious.

Management measures are further broken down for space heating, hot water heating, or other energy uses. The energy consumption profile used in the calculations is:

Residential Energy Demand: Distribution by Fuel Type

		Natural gas	Oil	Electricity
		(percent of sector energy use)		
SFD --	space heat/coal	29.8	3.8	5.9
	water heat	13.9	1.9	4.5
	other	0.7	—	13.1
	Sub-total	44.4	5.7	23.5
MUD --	space heat/coal	8.8	1.9	3.9
	water heat	4.9	1.0	1.9
	other	—	—	3.9
	Sub-total	13.7	2.9	9.7
	Total	58.3	8.6	33.2

Source: Based on national distributions.

Energy Efficiency Measures

Space Heating. Space heating accounts for the largest portion of residential energy use in British Columbia. The amount of energy consumed by space heating can be reduced through improvements in new housing, improved ventilation and enveloping in retrofit housing, heat pumps, high efficiency furnaces, and/or improved burners.

Water Heating. Water heating also accounts for a substantial portion of residential energy consumption. Relatively inefficient electric and gas heaters tend to dominate the market. Potential measures for reducing CO_2 emissions include: tank and line insulation, improved burner efficiency, and heat pump water heaters.

Lighting. The residential sector uses both incandescent and fluorescent lighting. Energy savings can be achieved by using energy saving lamps, tungsten-halogen lamps and compact fluorescent lamps instead of incandescent lighting. Energy savings with fluorescent lighting can be captured using high efficiency lamps, high efficiency ballasts, reflector inserts, timers and occupancy sensors, daylighting systems and metal halide or sodium lamps. These are all grouped together under the measure high efficiency lighting.

Other Measures. User education and practices can affect a variety of energy uses in this sector. Turning down thermostats, turning off unused lights and other "smart" energy practices can reduce emissions. As well, air conditioning improvements and energy efficient appliances and fixtures are considered.

Interfuel Substitution

The main energy substitutions to examine are shifts from light fuel oil (LFO) or natural gas to electricity for both water and space heating. In addition, solar measures are addressed.

6.3 Abatement Potential

The most significant abatement values are generated by interfuel substitution measures (see Exhibit 6.1). Summing across all applications, interfuel substitutions offer the following reductions in CO_2 emissions off the 1989 base:

Original Fuel: / Substitute Fuel:		CO_2 Emission Abatement (kt per year) LFO Electricity	Natural gas Electricity	LFO, gas Solar
SFD --	space heating/cooling	325	1,600	950
	water heat	165	765	670
MUD --	space heating/cooling	165	475	390
	water heat	85	270	170
Total		740	3,110	2,180
As % sector		12	50	35
As % province		0.8	3.4	2.3

As indicated, the largest absolute reductions can be generated from substituting electricity for natural gas. This result is driven by the large share of natural gas (about 60%) in total energy demand in this sector, coupled with the high percentage of electricity in B.C. that is generated by hydro.

However, we cannot assume that such significant increases in electricity demand as would occur with extensive natural gas substitution would be as environmentally benign as indicated by the low CO_2 emission factor. If shifts toward electricity result in additions to the fossil-fired power generating capacity or reduced exports to the U.S., the CO_2 emission factor would rise and the figures provided here would overestimate abatement potential. If such shifts bring forward large dam projects, the emission factor may stay low, but the public would have to choose between two quite different sets of environmental implications.[2]

Substantial reductions are also feasible from the extended use of solar power, especially as a complement fuel for space heating. Finally, conversions from oil to natural gas over the last decade have reduced oil's role in the energy picture and, hence, the absolute benefits of converting oil to electricity, even though oil has a much higher carbon content than natural gas.

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[2] Implications of different combination of meeting increased demand are discussed in Section 7.

Exhibit 6.1: Abatement Potential and Cost-Effectiveness for Management Measures in the Residential Sector

		Life of Measure	Annual CO_2 Reductions kt	Annual CO_2 Reductions % sector total	Lifetime CO_2 Reductions kt	PV Costs ($ million)	Cost-Effectiveness ($/t)
1.	User education/practices	50	530	8.4	26,440	-950	-36
2.	Air conditioning	20	<1	<0.1	5	60	positive
3.	High efficiency lighting	20	25	0.4	530	-240	-450
4.	Appliances and fixtures	20	10	0.2	175	-65	-375
Single Family Dwellings							
a)	*Space Heating*						
5.	Energy-efficient new housing[a]	50	865 to 1,4805	13.8 to 23.5	43,185 to 74,035	155 to 880	2 to 20
6.	Building envelope/ventilation retrofit[a]	30	615 to 1,110	9.8 to 17.8	18,516 to 33,315	280 to 840	8 to 45
7.	Heat pump	50	35	0.6	1,700	-205	-121
8.	Passive use of solar						
	a) LFO & natural gas	50	950	15.1	47,415	-435	-9
	b) electricity	30	40	0.6	1,945	-330	-170
9.	High efficiency furnace	30	335	5.4	10,025	50	5
10.	Improved burner efficiency	30	475	7.6	14,225	155	11
11.	Convert heat source						
	11.1 LFO to electricity	50	325	5.2	16,130	375	23
	11.2 Natural gas to electricity	50	1,600	25.5	80,025	3,040	38
b)	*Water Heating*						
12.	Tank/line insulation	50	250	4.0	12,535	-300	-24
13.	Improved burner efficiency	20	175	2.8	3,525	190	53
14.	Heat pump water heaters	20	25	0.4	525	-95	-184
15.	Direct use of solar						
	a) LFO & natural gas	20	670	10.7	13,355	1,435	108
	b) electricity	20	40	0.6	750	95	130
16.	Convert heat source						
	16.1 LFO to electric	20	165	2.6	3,290	130	40
	16.2 Natural gas to electric	20	765	12.2	15,340	1,045	68

continued...

Exhibit 6.1: Abatement Potential and Cost-Effectiveness for Management Measures in the Residential Sector (Cont'd)

		Life of Measure	Annual CO_2 Reductions kt	Annual CO_2 Reductions % sector total	Lifetime CO_2 Reductions kt	PV Costs ($ million)	Cost-Effectiveness ($/t)
Multi Unit Dwellings							
17.	Phase leading, load control & power	30	0.6	<0.1	20	-5	-269
a)	*Space Heating*						
18.	Energy-efficient new buildings[a]	50	295 to 425	4.7 to 6.7	14,835 to 21, 190	-455 to -260	-18 to -22
19.	Building envelope/ventilation retrofit[a]	30	170 to 255	2.7 to 4.0	5,345 to 8,020	-205 to -80	-14 to -25
20.	Plant efficiency/cogeneration	40	115	1.9	4,695	-90	-19
21.	Passive use of solar						
	a) LFO & natural gas	50	390	6.2	19,560	-240	-12
	b) electricity	50	35	0.5	1,630	-315	-192
22.	High efficiency furnace	40	290	4.6	11,605	-290	-25
23.	Convert heat source						
	23.1 LFO to electricity	50	165	2.6	8,225	185	22
	23.2 Natural gas to electricity	50	475	7.5	23,715	870	37
b)	*Water Heating*						
24.	Tank insulation/burner efficiency	30	70	1.1	2,045	-50	-24
25.	Heat pump water heater	30	5	0.1	190	-50	-253
26.	Direct use of solar						
	a) LFO & natural gas	30	170	2.7	5,070	-35	-7
	b) electricity	30	20	0.3	625	-180	-285
27.	Convert heat source						
	27.1 LFO to electricity	20	85	1.3	1,675	65	38
	27.2 Natural gas to electricity	20	270	4.3	5,410	345	64

a Range reflects range of energy saving estimates.

Significant reductions in CO_2 in both single family dwellings and multiple unit dwellings are also possible from:

- new energy-efficient housing (1160-1905 kt/yr);[3]
- building envelope/ventilation retrofits (785-1365 kt/yr);
- high efficiency furnaces and plant efficiency (740 kt/yr); and
- user education (530 kt/yr).

6.4 Cost-Effectiveness

Exhibit 6.1 indicates that there are numerous energy efficiency and interfuel substitution opportunities that can reduce CO_2 emissions while generating savings (i.e., the cost-effectiveness ratio is negative). Some measures, such as high efficiency lighting, heat pumps and appliances and fixtures (including motors) generate savings of over $200 per tonne CO_2 avoided. Other measures that could generate savings are:

- high efficiency furnace (MUD);
- tank/line insulation for hot water;
- user education; and
- phase leading and load control (MUD).

Energy-efficient new housing generates savings in the multi-unit dwelling buildings, but may not in all single family dwellings. This discrepancy is driven by cheaper unit capital costs and higher percentage energy savings for MUD's as a result of new designs. Similar results hold for building envelope/ventilation retrofit measures.

The most striking result of the cost-effectiveness analysis is that the measures that generate the largest reductions in CO_2 are not cost-effective (i.e. the cost-effectiveness ratio is positive). Specifically, conversion from oil to electricity would *cost* between $20 per tonne CO_2 and $40 per tonne CO_2 depending on the application (water/space heating; SFD/MUD) because the price of electricity is higher than the price of oil ($15.48/GJ for electricity as opposed to $7.63/GJ for oil). By the same logic, conversion from natural gas to electricity is even more expensive ($37 to $68 per tonne CO_2 removed) because the price differential between natural gas and oil is greater ($4.66/GJ vs. $15.48/GJ).

Application of passive solar energy to space heating in the residential sector could generate savings while reducing CO_2 emissions. This conclusion holds for any fuel type but are more pronounced for reductions in electricity use. Applied to both SFD and MUD using LFO or natural gas, about 1415kt/yr could be reduced with savings in excess of $5 per tonne. Cost estimates for direct use of solar energy for water heating are less conclusive. Savings can be generated in multiple unit dwellings but not necessarily in all single family dwellings. (In this case, savings are sensitive to capital costs which are higher per GJ saved in single family

[3] Ranges reflect range of energy savings considered possible.

dwellings than in multiple unit dwellings.) Overall, CO_2 reductions of some 230 kt/yr could be generated at some saving. However, the majority of savings (670 kt/yr) would cost about $110 per tonne CO_2 removed.

6.5 Summary

The following conclusions can be drawn from the above analysis:

- The most effective management measures from the perspective of reducing CO_2 emissions do not coincide with the major cost saving opportunities in the residential/agriculture sector. For example, of the five measures that yield the largest CO_2 reductions for single family dwellings, only one generates savings; of the five in the multi-unit sector, three generate savings.

- Solar energy for space heating in both single family and multiple unit dwellings offers one significant opportunity to reduce emissions and save money. Specifically, the cost-effectiveness ratio for passive solar space heating is (negative) $24 per tonne CO_2 reduced and (negative) $41 per tonne CO_2 reduced for single family and multiple unit dwellings, respectively ($30 per tonne averaged over both types of dwellings). Extensive application of solar space heating could reduce CO_2 emissions by about 22% of (1989) sector total emissions or about 1.5% of provincial emissions.

- Conversions from oil and natural gas to electricity would yield significant reductions in CO_2 emissions but would be costly. Because electricity is more expensive, each tonne of CO_2 saved will cost between $22 and $68 per tonne, depending on the application and the fuel replaced.

- The CO_2 savings from conversions to electricity are based on today's mix of electricity sources. If conversion is to be considered seriously, likely supply responses must be examined. If added demand is met by a new fossil-fuel fired generating station (for example), then CO_2 emissions will likely go *up*, not down. However, if more dams are the solution, the public must weigh the relative costs of local environmental damage with the global CO_2 issue. This issue is discussed in further detail in Section 7 Electricity Generation.

- Other management measures that could reduce CO_2 and generate cost savings are:

Measure	Cost-Effectiveness	Abatement
• user education	-$35/t CO_2	530 kt/yr
• water tank insulation (SFD)	-$25/t CO_2	250 kt/yr

In multiple unit dwellings, the following measures are also cost-effective:

Measure	Cost-Effectiveness	Abatement
• energy-efficient housing	-$20/t CO_2	295-425 kt/yr
• building retrofit	-$15-25/t CO_2	170-255 kt/yr
• high efficiency furnace	-$25/t CO_2	290 kt/yr

The CO_2 reductions from these five measures together represent less than 2% of total emissions for the province.[4]

- Reductions of CO_2 at no cost (or savings) in the residential/agriculture sector will be relatively small, accounting for no more than about 5% of total provincial emissions. More substantial reductions are possible through substitution toward electricity, but at some cost.

[4] Approximation only. Does not account for effects of energy savings of one measure on another measure's potential impact.

7.0 Electricity Generation

7.1 CO_2 Emissions

According to the 1988 inventory (B.H. Levelton, 1990), the electricity generating sector accounted for 1% of provincial CO_2 emissions rising to 6% by the year 2005. As discussed in Section 2 of this report, emissions have been revised to correspond to the most recent provincial energy forecast and base year. Under the new assumptions, electricity generation accounts for 4% of CO_2 emissions in 1989, rising marginally to 5% over the first decade of the next century. The differences are attributable to a higher share of gas in the early years and no coal-fired generation throughout the period.

In addition, this study separates out electricity generated in the pulp and paper sector from electricity that is part of the main B.C. Hydro grid. Electricity generation by pulp and paper plants is included Section 4 of this report. Under this breakdown, emissions from (B.C. Hydro) electricity generation accounts for about 3% of emissions in 1989, increasing by 8% over the next 20 years, but maintaining its share of total provincial emissions at about 3%.

The role of electricity generation in the management measures for CO_2 is not, however, restricted to reducing emissions associated with the base demand as forecasted by EMPR or B.C. Hydro. Some management measures suggested in other sectors focus on converting from oil, natural gas, etc. to electricity and are premised on continued reliance on hydro power to meet demand. In this section, we examine this premise and possible alternative strategies for meeting significant increases in electricity demand. However, we first examine the premise that hydro power is relatively CO_2 free.

7.2 Carbon Balance for Hydroelectric Dams

Throughout this report, electricity generated by hydro power has been attributed a zero emission factor; that is, we have assumed that hydro power generates no emissions of carbon dioxide. This assumption is consistent with the carbon dioxide emission inventory. However, some consideration of its validity is warranted.

Components that suggest hydro dams are not totally free of carbon dioxide emissions include:

- loss of forest cover and, hence, CO_2 uptake potential in the reservoir area; and
- emissions of carbon dioxide associated with the manufacture of cement, a major construction material for dams.

We are not aware of any comprehensive research conducted into the carbon balance for hydro dams, although B.C. Hydro is involved in the ongoing carbon balance project for B.C. and, specifically, the portion of the project that characterizes the carbon content of reservoirs (water

and sediment) compared with the carbon balance of forest areas. Field sampling is currently underway, but a report is not expected until late 1992 (B. Dinsmore, PowerTech pers.comm.).

In the absence of detailed analysis, the following observations are made. First, any CO_2 emissions related to the construction of hydro dams (while possibly significant during construction) will be spread out over many years and, over the life of the project, are likely to be insignificant.

Second, loss of forest cover would have to take into account harvesting of the area for commercial timber yields. For example, protected in perpetuity, the loss in carbon absorption capabilities/carbon storage could be significant. However, if the stand is scheduled for harvest within the same time frame as the dam, the incremental effect of the dam may be negligible.

Third, the reservoir itself can serve as a sink for CO_2. (The Levelton inventory estimated CO_2 uptake by sedimentation in provincial fresh water lakes at about 6.5-12 g C per m^2 per year, for a total uptake of 1,430 to 2,640 kt CO_2 per year.) Any loss in forest cover, therefore, will be at least partially offset by sedimentation uptake. The results of the carbon cycle project noted above should provide better estimates of the net effect of reservoirs.

The three factors explained above suggest that a zero emission factor for hydro is not entirely correct but that it is an acceptable approximation until further research provides a basis on which to estimate a more appropriate value.

7.3 B.C. Hydro's Electricity Plan

B.C. Hydro published a revised electricity plan for the province in March 1991 (B.C. Hydro, 1991) that documents B.C. Hydro's electricity demand and supply forecasts. The supply forecast identifies firm supply by source and by expected resource use. The following analysis is based on the expected resource use projections as they most clearly reflect the likely configuration of electricity generation, taking into account relative technical factors and cost attractiveness of different supply sources.[1]

As indicated in Exhibit 7.1 from the *Electricity Plan*, "total hydro" will continue to meet the bulk of demand over the long term. More particularly, all hydro sources -- which include "total hydro", "Alcan Purchase and Coordination", "Downstream Benefits" and "New Resources" --

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[1] In an earlier electricity plan (1990), a resource development priority list was developed. The same hierarchy underlies the 1991 plan. The priorities (in descending order) are:

- Power Smart;
- Coordination and purchases;
- Resource Smart;
- Private sector generation, self-generation and load displacement;
- New hydro generation in developed river basins; and
- New hydro generation in undeveloped river basins.

Exhibit 7.1: Forecast Energy Demand and Expected Resource Use

Panel a) Expected Resource Use (millions of kWh)

Resource	1991/92	1994/95	1997/98	2000/01	2005/06	2010/11
Hydro						
Total Hydro	47,100	47,370	47,890	47,860	48,300	48,940
Alcan Purchase & Coordination	180	950	2,690	2,750	2,830	2,780
Downstream Benefits	0	0	0	2,790	4,800	4,520
New Resources	0	0	0	0	0	10,500
Sub-Total	***47,280***	***48,320***	***50,580***	***53,400***	***55,930***	***66,740***
Thermal						
Burrard	2,500	3,010	2,730	2,670	3,580	0
Gas Turbines	0	0	0	10	90	90
Alberta Purchases	90	190	100	150	570	510
Sub-Total	***2,590***	***3,200***	***2,830***	***2,830***	***4,240***	***600***
Signed IPP's	0	1,700	1,700	1,700	1,700	1,700
Total Expected Resource Use	***49,870***	***53,220***	***55,110***	***57,930***	***61,870***	***69,040***

Panel b) Expected Resource Use (Percent of Total)

							Averages	
Resource	1991/92	1994/95	1997/98	2000/01	2005/06	2010/11	1991/92 to 2000/01	1991/92 to 2010/11
Hydro								
Total Hydro	94.4	89.0	86.9	82.6	78.1	70.9	87.8	82.0
Alcan Purchase & Coordination	0.4	1.8	4.9	4.7	4.6	4.0	3.3	3.8
Downstream Benefits	0.0	0.0	0.0	4.8	7.8	6.5	1.1	4.0
New Resources	0.0	0.0	0.0	0.0	0.0	15.2	0.0	3.0
Sub-Total	***94.8***	***90.8***	***91.8***	***92.2***	***90.5***	***96.7***	***92.2***	***92.8***
Thermal								
Burrard	5.0	5.7	4.9	4.6	5.8	0.0	5.2	4.2
Gas Turbines	0.0	0.0	0.0	<0.1	0.1	0.1	0.0	<0.1
Alberta Purchases	0.2	0.4	0.2	0.3	0.9	0.7	0.2	0.45
Sub-Total	***5.2***	***6.0***	***5.1***	***4.9***	***6.8***	***0.9***	***5.4***	***4.7***
Signed IPP's	Ø	3.2	3.1	2.9	2.7	2.5	2.4	2.5
Total Expected Resource Use*	***100.0***	***100.0***	***100.0***	***100.0***	***100.0***	***100.0***	***100.0***	***100.0***

Notes: * Numbers may not add due to rounding.
Source: B.C. Hydro (1991)

make up most of projected resource use. (Note: Some Independent Power Producer (IPP) contracts will include small hydro projects, but it is likely that the larger projects will be gas-fired (L. Wells, B.C. Hydro, pers. comm.). IPP's have, therefore, not been included in hydro supply figures.) The remaining power sources are natural gas ("Burrard", "Gas turbines") and wood waste ("Self-generation").

Panel b) in Exhibit 7.1 clearly sets out the role of hydro in total resource use. The percentage shares are calculated net of self-generation for reasons discussed above. As shown, hydro maintains a fairly steady share of total resource use of 92% to 97% through the forecast period. Specifically, hydro's share falls in the early 1990's, rises temporarily around the turn of the century and rises again with the introduction of new hydro projects between 2005/6 and 2010/11. Averaged over 10-year intervals, hydro's share remains relatively constant at 92%.[2]

If an agressive CO_2 management strategy is adopted and conversion to electricity proceeds, the demand for electricity could rise significantly. If, for example, all oil space heating in the residential sector (single family and multiple unit dwellings) is converted to electricity, electricity demand would increase approximately 3%. If conversions from natural gas are included, electricity demand in the Province could increase almost 25%. The associated increase in B.C. Hydro demand load (which excludes self-generated electricity) would be about 30%.

The B.C. Hydro *Electricity Plan* does not explicitly examine such a large increase in demand. They do, however, hypothesize a high growth scenario in which demand is about 10% higher than their base case after ten years. In such a case, the Plan calls for a new hydro project (such as Peace Site C) to come on stream as much as eight years earlier. This suggests that hydro remains the fall back resource and that the share of hydro in total supply would likely to remain at or exceed 92% even under significant demand pressures.

A closer look at the incremental sources of electricity supply is, however, warranted because of the significant implications for any measures that suggest conversion to electricity, and because a recent report suggests that conversion from natural gas to electricity could actually increase CO_2 emissions (Marvin Shaffer, 1991).

7.4 Incremental Sources of Electricity Supply

B.C. Hydro has a number of options available to meet an increase in demand. These include more hydro, increased use of Burrard thermal plant, construction of new thermal plants, reduced exports to the United States and Alberta, and increased Alberta purchases. The actual mix of resources used will depend on a number of factors, including:

- magnitude of increase in demand;
- rate of increase in demand;

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[2] This figure corresponds to the 1989 share that was used to estimate potential emission reductions associated with conversions to electricity in previous chapters.

- sequencing of CO_2 management measures that affect (i.e., increase or decrease) demand for electricity;
- CO_2 policy measures to influence resource choice; and
- a variety of other political, economic and social factors.

As noted above, a package of CO_2 measures could potentially increase electricity demand by more than 30%, over a time frame that would be (at least partially) dictated by CO_2 policy measures. To assess possible resource responses, we have chosen the following time profile for demand increases:[3]

- 5% increase by 1995/96
- 10% increase by 1997/8
- 20% increase by 2000/01
- 30% increase by 2000/01.

Two strategies for meeting this demand provide very different pictures of possible impacts on CO_2 emissions.

CO_2-Intensive Strategy: A "CO_2-intensive" strategy would see demand increases met by:

- increased purchases from Alberta;
- reduced exports from the United States and Alberta; and
- use of Burrard thermal plant's full capacity.

Hydro resources would be increased only after these three options have been used to their maximum. This strategy corresponds to the mix of sources used in Shaffer's simulation of a 5% increase in demand.

The resulting CO_2 emission factors for incremental demand for electricity are shown in Exhibit 7.2. Because Alberta, the United States and Burrard are combinations of coal, oil and natural gas-fired, their emission factors are high -- ranging from 90 t/TJ for coal to 49.68 t/TJ for natural gas. Because there is sufficient "capacity" in these three sources to meet a 15% increase in demand, the CO_2-intensive supply response yields high emission factors for incremental electricity supply up to 15%.

However, these three sources do have limited capacity.[4] If demand increases significantly (i.e., more than 15%), new hydro resources would be brought on stream, lowering emission factors close to that associated with a 30% increase in demand (see Exhibit 7.2).

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[3] Note: This profile is illustrative only. It is not based on any policy scenario.

[4] Natural gas capacity is virtually unlimited if new thermal plants are considered. However, B.C. Hydro's *Electricity Plan* indicates that the corporation would bring new hydro resources on stream before building new (non-IPP) natural gas plants.

Exhibit 7.2: Incremental Electricity Supply and Associated CO_2 Emission Factors

Increase in Demand	Emission Factors[a] (tonnes CO_2/TJ)	
	CO_2 Intensive Response	Hydro-Intensive Response
5%	61.45	19.32
10%	60.07	4.12
20%	45.56	0
30%	31.24	13.28

a For incremental supply.

Source: The ARA Consulting Group.

Hydro-Intensive Strategy: The alternative to the CO_2-intensive strategy is a hydro-intensive response. In this case, hydro potential is used to its maximum, with Resource Smart projects and new resources brought on stream as early as possible.[5] Earliest in-service dates and energy availability from hydro resources are assumed to be:

• Resource Smart projects		
- Waneta, Brilliant	1995/6	1540 GWh/yr
- Other	2000/01	1365 GWh/yr
• Lower Columbia Development[6]	1996/7	3000 GWh/yr
• Peace Site C	1998/9	4710 GWh/yr.

The CO_2 emission factors associated with this response, which are given in the last column of Exhibit 7.2, are *significantly* lower than in the previous strategy. Specifically, they are sufficiently low at all demand levels to generate CO_2 abatement benefits similar (or greater than) those calculated in this report.[7] A maximum of 10,615 GWh/yr (about a 20% increase in demand) could be met by these new resources. To meet demand increases in excess of 20%, entirely new hydro projects would have to be introduced or the system would have tap into its fossil fuel options (e.g., reduced U.S. exports and increased utilization of Burrard plant capacity). The rise in the emission factor for a 30% increase in demand in Exhibit 7.2. reflects this option; should new hydro resources be available, the emission factor for incremental demand would remain at zero.

The pace of demand increase is central to the viability of the hydro-intensive option. Should demand increase rapidly (e.g., 20% by 1995/6), Waneta and Brilliant could provide some added power, but sufficient hydro resources could not be brought on quickly enough to meet demand and CO_2-intensive resource options (i.e., U.S. exports, Alberta purchases and Burrard) would be required, which would raise the emission factor to about 49 t/TJ. At this level, conversion of oil to electricity would reduce CO_2 emissions, but overall benefits from conversion from natural gas would largely depend on energy savings from relative appliance efficiencies.[8]

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5 Downstream Benefits and Alcan Purchases are constrained by legal agreement and do not offer much latitude in advancing the availability of the power.

6 Murphy Creek and Border projects.

7 CO_2 abatement from interfuel substitution measures is calculated using an emission factor based on today's mix of electricity sources (i.e., 12.32 t/TJ).

8 The results for the residential sector of sensitivity tests using emission factors from a CO_2-intensive strategy are presented in Appendix D.

A sensitivity analysis was done to examine the impact of a CO_2-intensive response to increased demand in the residential sector. Using an electricity emission factor of 60.07 t/TJ (corresponding to a 10% increase in demand by 1997/8 -- see Exhibit 7.2), conversion from LFO and natural gas to electricity still generates CO_2 reductions due to energy savings from higher efficiency factors for electric space and water heating appliances. However, the reductions are significantly smaller: about 0.6% of total provincial CO_2 emissions compared with about 4% with an emission factor of 12.32 t/TJ. The different emission factors further increase the cost per tonne of conversions.

If one assumes that reductions in energy demand through conservation measures are dedicated to the same mix of resource uses, then electricity conservation projects appear more attractive than in the base estimates. For example, if energy-efficient new single family housing results in a 35% decrease in electricity consumption and that available energy is used to increase exports to the United States or reduce purchases from Alberta, then emission abatement would be higher (970 kt/yr) than under an emission factor of 12.32 t/TJ (865 kt/yr). The higher emission factor also lowers the cost of the measure marginally.

In conclusion, resource management decisions by B.C. Hydro can affect CO_2 abatement potential of conversions to electricity and measures that promote conservation of electricity. The estimates of CO_2 abatement from fuel switching that are presented in Sections 3 through 6 assume a supply response that favours hydro, but does not reflect the maximum reductions possible if a hydro-intensive strategy were followed. Adoption of a CO_2-intensive supply response would increase the attractiveness of electricity conservation measures and decrease the attractiveness of conversions. For conversions, CO_2 emission reductions would still be generated (but would fall to insignificant levels), and the cost per tonne CO_2 abated would increase.

7.5 Management Measures

On the premise that hydro power is associated with relatively minor CO_2 emissions, the primary management measure in B.C. would be to place more emphasis on hydro power at the expense of gas and oil-fired generation. This general policy can be implemented both for the general electricity plan and for strategies to meet incremental demand arising from CO_2 management measures.

First, in terms of the B.C. Hydro *Electricity Plan*, this policy would:

- favour small hydro over fossil fuel IPP's, perhaps through an environmental price credit;
- reduce use of Burrard thermal plant further;[9] and

[9] Firm supply from Burrard is 5270 GW.h compared with the projected use of 2500-3140 GW.h in B.C. Hydro's *Electricity Plan*. Burrard accounts for approximately 5% of total demand throughout the period.

- maximize generation from wood residue and power savings from Power Smart/Resource Smart programs.

B.C. Hydro's *Electricity Plan* does not include any alternative energy sources, although different options are discussed. The conclusions reached are:

• solar (photovoltaic):	• uneconomic because of low energy yields in B.C.;
• wind generation:	• uneconomic for on-grid generation;
• tidal power:	• high costs and environmental impacts;
• wave conversion:	• still at prototype stage of development;
• hydrogen:	• recent technology developments are being examined; and
• geothermal:	• potential private development at Meager Creek.

Apart from technology problems, alternative energy sources generally exceed the cost of conventional gas turbine systems by a factor of two to five (see Exhibit 7.3) and, therefore, are unlikely to be a cost-effective approach to CO_2 management.

In terms of choices of marginal supply of electricity, CO_2 management priorities clearly call for adoption of a hydro-intensive response to meeting increased demand that may materialise from other CO_2 management measures. As indicated above, if demand increases are significant (e.g., 20%) and are paced over the next decade, a hydro response would be feasible and CO_2 emission reductions could be more pronounced than estimated in Sections 3 through 6 of this report. If, however, demand increases are sudden or unexpected, they could risk an overall increase in CO_2 emissions. From the perspective of management measures, then, an aggressive CO_2 abatement strategy that included high cost options such as conversions from natural gas and oil to electricity, must be coordinated with electricity supply response policies.

7.6 Summary

The primary conclusions from the above discussion are:

- A general assumption that hydro power releases very little carbon dioxide appears reasonable based on a casual observation that the CO_2 emissions related to cement manufacture and loss of CO_2 sinks related to flooding of forest areas are minor when assessed over the entire life of the dam. Further work in this area is ongoing (Dinsmore, 1991 pers.comm.).

- Hydroelectric power represents a significant resource that reduces B.C.'s emissions well below comparable electricity-related emissions in jurisdictions that rely on coal, oil and gas-fired generation.

- The opportunities for reducing CO_2 emissions from the electrical generating sector from current levels are limited. Some reduction (e.g., 2200 kt or 2% of provincial emissions) could be garnered by eliminating Burrard thermal generation. This option could, however, restrict the utility's capability to satisfies peak demand without significantly adding to base load hydro capacity. The role of alternative energy sources is still a long term proposition in B.C., with the exception of some geothermal developments.

- Considerable hydro potential exists in B.C. to meet significant increases in demand. However, most of this capacity could not be brought on stream before the mid-to late 1990's so that a rapid increase in demand over the next few years would have to be met by reducing exports to the United States, increasing generation at the Burrard thermal plant (or building new natural gas plants) or increasing purchases from Alberta. This response could result in an *increase* in overall CO_2 emissions. Any CO_2 management measures that encourage use of electricity over natural gas or fossil fuel, then, should be coordinated with policies that support the choice of hydro over non-hydro options.

8.0 CO_2 Extraction and Geoengineering

Most of the measures described above focus on reducing consumption of high carbon energy types. This focus is very different from many pollution strategies that have concentrated on end-of-pipe solutions. In this section, we briefly examine the options to interfuel substitution and energy conservation, namely, CO_2 extraction technologies and techniques to enhance sinks other than forests.

8.1 CO_2 Extraction and Disposal

One alternative for reducing emissions is to extract and dispose of CO_2; however, several major concerns with CO_2 extraction remain.

The first problem is disposal. CO_2 extracted from power plant flue gases can be disposed of by injecting it into exhausted natural gas reservoirs, abandoned caverns, aquifers and deep oceans. Currently, research is being undertaken on the potential to convert CO_2 into solid or liquid form (for more convenient disposal) as the number of natural gas reservoirs and caverns are limited. The major industrial use of CO_2 is the flooding of reservoirs for enhanced oil recovery. Industry does consume a certain amount of CO_2 in carbonated beverages, as dry ice, as an aerosol propellent in fire extinguishers and in various other ways. Unfortunately, these markets are limited and once consumed, CO_2 is released back into the atmosphere. Production of polycarbonate, polyurethanes and other plastics permanently fix CO_2 but require hydrogen which is commonly produced from a process that in turn produces CO_2. It appears that any control program of significant scope would necessarily require large disposal costs as the volume of CO_2 produced dwarfs existing markets for reuse and acts as a constraint on the viability of the option (Lashof and Tirkpak, 1990).

Also of concern is the cost of CO_2 extraction. As shown in Exhibit 8.1, CO_2 scrubber costs are in the order of three to four times more expensive than SO_2 scrubbers, and are still technologically relatively immature. These cost estimates exclude possible additional costs of transportation and disposal of CO_2.

The final difficulty with extraction is applicability. A recent study by Energy Mines and Resources Canada claims that approximately 12% of Canada's CO_2 emissions have the potential for extraction and disposal. In Alberta, 75% of CO_2 emissions are from industry and electricity generation and the Alberta Oils and Technology Research Authority (AOSTRA) considers CO_2 disposal to be a viable option in Alberta. In British Columbia, however, the opportunity for significant removal is limited because close to half of emissions in the province are from inconveniently distributed sources such as individual industries. The potential for CO_2 disposal from pulp and paper plants may, however, be worth investigation. To our knowledge, there have been no studies examining CO_2 disposal from biomass fuels and it is not clear whether the technology from coal combustion can be adapted.

Exhibit 8.1: CO_2 Scrubber Costs Compared to SO_2 Scrubber Costs[a]

	CO_2 Scrubber	SO_2 Scrubber[c]
Capital Cost ($/kw)[b]		
Scrubber	810	220
Pipeline/Disposal	80-710	n/a
Variable Operation and Maintenance Costs (mills/kwh)	n/a	3.5
Energy Penalty (%)	25	4.5
Capacity Penalty (%)	22	2.5
Fixed Operation and Maintenance Costs ($/kwyr)	n/a	10
Total Cost (mills/kwh)[d]	36-47	10.7

Notes:
a 90% removal of both CO_2 and SO_2.
b Greenfield site.
c 1987 EPA Interim Acid Rain Base Case Estimates.
d 65 percent capacity factor; 9 percent capital charge rate; incremental power costs 65 mills per kilowatt-hour; new plant costs of $1,200/kw; fixed O&M for CO_2 scrubber is assumed to be ten dollars per kilowatt-year for comparison purposes only, actual costs could well be higher; 1988 dollars assumed to be worth 42 percent less than 1980 dollars.

Source: Lashof & Tirpack (1990).

CO_2 extraction is often dismissed in policy discussions as it is site specific, and considered undefined and costly. Difficulties lie with lack of data on feasibility (i.e., potential costs and benefits) and the uncertainty of the current technology to capture, store, purify and transmit the CO_2. In the B.C. context, limited application to non-standard sources coupled with the disposal issue suggests that CO_2 extraction be considered as a long term measure that requires much more research.

8.2 Geoengineering

Reducing CO_2, or any greenhouse gas is a global concern. If reductions in emissions prove too difficult to achieve, global scale geoengineering options could be considered to counter global warming. Geoengineering entails mitigating temperature increases by screening sunlight and stimulating ocean uptake of CO_2. Sunlight screening can be achieved by space mirrors, stratospheric dust, multiple balloons, stratospheric soot and stimulation of cloud condensation nuclei (Exhibit 8.2). These options have the potential to significantly reduce greenhouse warming.

While geoengineering options are considered technically and economically feasible, the U.S. National Academy of Science (1991) cautions that these measures must be evaluated with extreme care as the possible environmental side-effects are unknown. Furthermore, many would present a philosophical argument against geoengineering and CO_2 extraction, suggesting that the only long term solutions to global warming lie with eliminating its causes rather than further manipulating natural systems.

Exhibit 8.2: Geoengineering Techniques to Counteract Global Warning

Sunlight Screening	
Space Mirrors	Place 50,000 100-km^2 mirrors in the earth's orbit to reflect incoming sunlight.
Stratospheric Dust[a]	Use guns or balloons to maintain a dust cloud in the stratosphere to increase the sunlight reflection.
Stratospheric Bubbles	Place billions of aluminized, hydrogen-filled balloons in the stratosphere to provide a reflective screen.
Low Stratospheric Dust[a]	Use aircraft to maintain a cloud of dust in the low stratosphere to reflect sunlight.
Low Stratospheric Soot[a]	Decrease efficiency of burning in engines of aircraft flying in the low stratosphere to maintain a thin cloud of soot to intercept sunlight.
Cloud Stimulation[a]	Burn sulfur in ships or power plants to form sulfate aerosol in order to stimulate additional low marine clouds to reflect sunlight.
Ocean Biomass Stimulation	Place iron in the oceans to stimulate generation of CO_2-absorbing phytoplankton.

a These options cause or alter chemical reactions in the atmosphere and should not be implemented without careful assessment of their direct and indirect consequences.

Source: National Academy Press, (1991) Policy Implications of Greenhouse Warming.

9.0 Discussion of Promising Measures

As noted in the introduction to this report, the analysis of abatement potential and cost-effectiveness provides the first step in identifying management measures that make sense in the British Columbian context. In this section, we pull the sector results together to identify the more promising measures across all possibilities. Once the promising measures are identified (based on abatement potential and cost-effectiveness), they are examined in greater detail, taking into account other factors that are important to their effectiveness and viability. Finally, the promising measures are categorized as to relative attractiveness, taking into account cost-effectiveness, abatement potential, barriers to implementation and time frame of impacts.

9.1 Identification of Promising Measures

Analysis of the four "first tier" sources of CO_2 emissions in B.C. suggests that there are numerous measures that can be taken to reduce CO_2 in the province at no cost, or possibly savings, from a commercial or private perspective.

To illustrate the most promising measures across the four main sectors, we have categorized them according to abatement potential and cost-effectiveness (see Exhibit 9.1). The categories are based on the summary of abatement potential and cost-effectiveness estimates in Exhibit 9.2 and are defined as follows:

- **abatement potential**
  - high — more than 2% of total provincial emissions (1989 base)
  - moderate — 0.5 to 2% of total provincial emissions
  - low — less than 0.5% of total provincial emissions.
- **cost-effectiveness**
  - high — savings are generated
  - moderate — CO_2 reductions can be achieved at a cost of no more than $10 per tonne
  - low — cost of reduction greater than $10 per tonne.

Measures with high abatement potential are dominated by forest and forest industry measures whereas as highly cost-effective measures are more numerous in the residential and transportation sectors. Given this distribution, it is not surprising that there are only two measures that are *both* highly cost-effective and have high potential for CO_2 reductions. These measures are:

- a package of energy efficiency measures in the pulp and paper industry; and

Exhibit 9.1: Preliminary Categorization of Management Measures

	High Abatement Potential (>2% provincial emissions)	Moderate Abatement Potential (0.5% to 2% provincial emissions)	Low Abatement Potential (<0.5% provincial emissions excluding <50kt per year)
High Cost-effectiveness (cost savings)	**Road Transportation** ❑ Vehicle fuel efficiency **Pulp and Paper** ❑ General efficiency measures	**Pulp and Paper** ❑ Substitution to natural gas **Residential** ❑ User education/practices ❑ Passive solar (space heating) **Road Transportation** ❑ Driver training ❑ Route & traffic planning ❑ Vehicle maintenance ❑ Conversion to natural gas ❑ Conversion to propane ❑ Public transportation ❑ Trip reduction measures	**Residential** ❑ High efficiency furnace (MUD) ❑ Energy-efficient new housing (MUD) ❑ Building envelope retrofit (MUD) ❑ Plant efficiency/cogeneration ❑ Tank/line insulation ❑ Direct solar (water heat; MUD; LFO & natural gas) **Road Transportation** ❑ Vehicle retrofits (commercial diesel) ❑ Conversion to diesel (commercial) ❑ Staggered work hours, etc.
Moderate Cost-effectiveness ($0 - $10 per tonne CO_2)	**Forests and Forest Management** ❑ Utilization of harvest residues & wastes ❑ Plant NSR lands ❑ Plant marginal agricultural lands **Pulp and Paper** ❑ Process changes ❑ Substitute to 100% self-generated fuels	**Forests and Forest Management** ❑ Human-caused fire prevention ❑ Enhance forest productivity **Residential** ❑ Energy-efficient new housing (SFD) ❑ Improved burner efficiency (space heat) **Road Transportation** ❑ Intermodal shift (road to rail)	**Forests and Forest Management** ❑ Plant specific locations **Residential** ❑ High efficiency furnace (SFD)
Low Cost-effectiveness (>$10 per tonne CO_2)	**Residential** ❑ Convert natural gas to electricity **Forests and Forest Management** ❑ Whole tree clipping	**Residential** ❑ Direct solar (water heat; SFD; LFO & natural gas) ❑ Building envelope retrofit (SFD) ❑ Convert LFO to electricity	**Residential** ❑ Improved burner efficiency (water heat) **Road Transportation** ❑ Vehicle retrofits (private vehicles) ❑ Vehicle retrofits (commercial, non-diesel) ❑ Conversion to diesel (private)

Exhibit 9.2: Summary of Abatement Potential and Cost-effectiveness

	Annual Reduction in CO_2 (kt) [a]	Percent of Total Provincial CO_2 emissions [a]	Cost-effectiveness ($/t, rounded)
Forests & Forest Management [a]			
Human-caused fire prevention	540	0.6	?
Utilization of harvest residues	2210	2.4	f
Whole tree chipping	2610	2.8	>0
Fuel pellets -- domestic	120	0.1	f
Fuel pellets -- export	335	0.4	f
Export for cogeneration	1580	1.7	f
Plant NSR lands	2360-3020	2.5-3.3	2-3
Plant marginal agricultural land (with pastureland)	1790-2290	1.9-2.5	1-2
Plant specific locations	125-130	0.1	1
Enhance forest productivity (with pastureland)	295-1125	0.3-1.2	3-10
Pulp and Paper [b]			
General efficiency improvements	4400	4.8	<0
Substitute recycle for kraft	1945	2.1	g
Substitution to 100% self-generated fuels	3805	4.1	h
Substitution to natural gas	445	0.5	-40 i
Road Transportation [c]			
Driver training	515	0.6	-30 to -40
Route & traffic planning	765	0.8	-80
Vehicle maintenance	540	0.6	-15 to -65
Vehicle retrofits			
a. private vehicle	65	0.1	445
b. commercial diesel	60	0.1	-90

Exhibit 9.2: Summary of Abatement Potential and Cost-effectiveness (continued)

	Annual Reduction in CO_2 (kt)[a]	Percent of Total Provincial CO_2 emissions[b]	Cost-effectiveness ($/t, rounded)
c. commercial non-diesel	100	0.1	40
Vehicle fuel efficiency	2010	2.2	-40 to -100
Fuel conversion			
a. MOG to natural gas	955	1.0	-180 to -330
b. MOG to propane	895	1.0	-365 to -520
c. MOG to diesel (private)	310	0.3	200
d. MOG to diesel (commercial)	345	0.4	-100
Staggered work hours etc.	115	0.1	-80
Trip reduction measures	320	0.4	-80
Public transportation	580	0.6	-10
Intermodal shift	785	0.9	?
Residential / Agriculture[d]			
User education / practices	530	0.6	-35
Air conditioning	<1	<0.1	positive
High efficiency lighting	25	<0.1	-450
Appliances & fixtures	10	<0.1	-375
Phase leading, lead control & power	<1	<0.1	-270
Space Heating			
Energy-efficient new housing			
a. single family	865-1485	0.9 to 1.6	2 to 20
b. multiple unit	295 to 425	0.3 to 0.5	-20
Building envelope retrofit			
a. single family	615 to 1110	0.7 to 1.2	8 to 45
b. multiple unit	170 to 255	0.2 to 0.3	-15 to -25
Heat pump	35	<0.1	-120
Passive use of solar			
a. LFO & natural gas	1340	1.5	-10
b. electricity	75	0.8	-170 to -190
High efficiency furnace			
a. single family	335	0.3	5

Exhibit 9.2: Summary of Abatement Potential and Cost-effectiveness (continued)

	Annual Reduction in CO_2 (kt)[e]	Percent of Total Provincial CO_2 emissions[e]	Cost-effectiveness ($/t, rounded)
b. multiple unit	290	0.3	-25
Improved burner efficiency	475	0.5	10
Convert heat source			
a. LFO to electricity	490	0.5	25
b. Natural gas to electricity	2075	2.2	40
Plant efficiency / cogeneration	115	0.1	-20
Water Heating			
Heat pump water heater	30	<0.1	-185 to -255
Direct use of solar (single family)			
a. LFO & natural gas	670	0.7	110
b. electricity	40	<0.1	130
Direct Use of Solar (multiple unit)			
a. LFO & natural gas	170	0.2	-5
b. electricity	20	<0.1	-285
Tank / line insulation (single family)	250	0.3	-25
Improved burner efficiency (single family)	175	0.2	55
Tank insulation / burner efficiency (multiple unit)	70	<0.1	-25
Convert heat source			
a. LFO to electricity	250	0.3	40
b. Natural gas to electricity	1035	1.1	65

Notes:

a. See notes to Exhibit 3.2
b. See notes to Exhibit 4.4
c. See notes to Exhibit 5.5
d. See notes to Exhibit 6.1
e. Based on 1989 emissions
f. Depends on specifics of each use
g. Depends on specifics; some ventures could be profitable, but these are likely limited in number
h. Excludes capital costs. Likely only viable as part of new plants or major capital projects.
i. Energy savings only

- vehicle fuel efficiency improvements.

An improvement in average vehicle fleet fuel efficiency of 17% over the next decade could generate emissions reductions of about 2000 kt per year, or about 2.2% of the provincial total. General efficiency measures in the pulp and paper industry, similar to the efficiency and fuel type changes made over the last 15 years, could directly reduce emissions by some 4400 kt per year, or about 4.7% of provincial emissions. In both cases, measures would be phased in over the next decade.

Measures that fall into the category of high potential for abatement with moderate cost-effectiveness are:

- various forestry management measures, including:
  - replanting NSR lands;
  - planting marginal agricultural lands;
  - increased utilization of harvest residues and wood residues;
- two pulp and paper measures:
  - process changes that favour low energy, high fibre utilization methods;
  - increased substitution of fossil fuels by self-generated fuels.

These results should be interpreted with care. First, the increased utilization measure is loosely defined, with no specific products specified. Market and technical feasibility studies for new products/uses were well outside the scope for this project. However, we feel it appropriate to maintain attention on the fibre utilization issue because illustrative scenarios suggest that abatement potential could be significant and there is some potential for cost-recovery. Similarly, process changes could be viable in some situations and the potential for CO_2 abatement is sufficiently significant to warrant closer assessment.

Many more measures generate savings with moderate potential for CO_2 abatement. Except for complete substitution to natural gas in the pulp and paper industry, all these measures are in the residential and transportation sectors:

- residential measures:
  - passive solar for space heating;
  - user education regarding conservation practices.
- transportation measures:
  - conversion of vehicles to natural gas or propane;
  - route and traffic planning;
  - vehicle maintenance;

- driver training;
- trip reduction measures;
- increased use of public transportation.

Each of these measures generate cost savings ranging from $8 per tonne CO_2 removed (public transportation) to as high as $500 per tonne (conversion to propane). Abatement potential exceeds 485 tonnes per year for each measure.

Combinations of measures that could collectively produce moderate CO_2 reductions at little or no cost include:

- a package of energy efficiency measures for road transportation, including staggered work hours and consolidated work week and vehicle retrofits; and

- various energy efficiency measures for the multiple unit dwelling sector, including energy-efficient new buildings, building envelope/ventilation retrofit improvements, high efficiency furnaces, plant efficiency/cogeneration and tank/line insulation for hot water tanks.

Finally, only two measures with high abatement potential are associated with high costs:

- conversion of residential buildings from natural gas to electricity (because of the high cost of electricity relative to natural gas, the cost-effectiveness value exceeds $20 per tonne CO_2 reduced); and

- whole tree chipping.

A few measures are excluded from Exhibit 9.1. These measures fall into two groups. The first group includes measures for which estimates of abatement potential and/cost-effectiveness could not be generated. These measures include site treatment (forests and forest management) and land use planning (transportation) and will be considered in the remainder of the report. The second group includes electric cars, methanol/ethanol fuel, and hydrogen in the transportation sector and carbon dioxide scrubbers which represent measures that are currently unproven but that may emerge as viable options in the future.

The analysis brings out four critical factors that affect the relative importance of management measures and, indeed, the nature of a realistic CO_2 strategy for B.C. These factors are:

- The forests of B.C. represent a huge sink for the province. By sheer land mass, management of the forests for CO_2 control along with other goals, could yield significant CO_2 reductions.

- Wastes from the forest products industry -- from harvest residues through to wood residues and black liquor through to post-consumer paper -- generate large emissions of CO_2. The pulp and paper industry has made good use of these waste products as

energy and, in so doing, has reduced CO_2 emissions from fossil fuels. Further energy conservation and substitution in the pulp and paper industry will make a difference; however, significantly reducing CO_2 emissions from harvest residues and other wood residues will be as important to the overall CO_2 profile of the province.

- The importance of forest and forest industry measures are also defined by the timeframe over which CO_2 reductions are considered. For example, emission benefits for re/afforestation are not on-going. These measures have a finite life of about 80 years, after which time other measures and (hopefully) new technologies will have to take up the slack. Secondly, the debate over the net carbon balance of preservation of old growth forests vs. the harvest/regeneration cycle also depends on the timeframe: old growth preservation and, similarly, utilization of wood residues makes more sense in the short run when considerable fibre from the harvest is burned as energy and waste (only a portion remains locked in durable products) at the same time as establishment and growth of seedlings absorbs only a modest amount of CO_2.

- Numerous transportation and residential measures are cost-effective, although the impact on CO_2 abatement is not as impressive as for many of the forest and forest industry measures. In these sectors, it will be necessary to consider a package of management measures.

- Proven alternative fuels could play an important role in CO_2 control. Specifically, application of passive solar systems to residential space heating is cost-effective as is conversion of vehicles to propane or natural gas. Other alternative fuels, especially in the transportation sector and those that can use wood residues as a feedstock, will need further research and development, but could be important to a long-run strategy for CO_2 management. Similarly, research and battery developments could push electric vehicles into the transportation mainstream within the next 30 years, with significant CO_2 benefits.

- The province has a valuable hydroelectric resource that offers the opportunity to convert to electricity in the industrial, residential, and commercial sectors. However, the viability of this set of measures is limited by high electricity prices relative to other fuels and potential trade-offs with other environmental concerns. Also, the CO_2 abatement potential of these measures is premised on meeting increased demand predominantly with a hydro resources. Although hydro resources are available to meet this demand, policies to encourage the use of electricity should be accompanied by policy support and incentives to use hydro power over other sources of incremental supply of electricity.

In summary, a number possible management measures could reduce CO_2 emissions at little or no cost. The measures of most interest are bounded by the heavy lines in Exhibit 9.1 and include measures from each of the sectors examined. However, the moderate to high indicators do not mean that the measures will be easy to implement as other institutional factors may impinge on their viability. These barriers are discussed in Section 9.3.

9.2 Promising Measures -- Social Cost Perspective

The analysis in this study has focused on the attractiveness of individual measures from a commercial or private perspective; that is, the "economics" from the perspective of the individual/company implementing the measure. However, the benefits/costs of a measure can differ when viewed from the perspective of society as a whole. In this section, the implications of a social cost perspective are briefly addressed. The purpose of the section is to indicate how social and private costs may differ and to suggest the extent to which those differences may affect the set of promising measures identified in the previous section.

There are two main reasons for a discrepancy between social and private costs of individual measures:

- different discount rates; and
- different energy prices.

Energy prices that an individual faces differ from the true economic costs faced by society as a whole for two reasons. First, retail prices include taxes (e.g., road tax, federal excise tax on transportation fuels). Although a cost to the individual, taxes are simply a transfer from one part of society (the individual) to another (the government). There is no overall cost to the Province as a whole. In calculating the social cost of measures, then, taxes must be netted out of prices.

Second, many energy prices are regulated so that the retail price is not a good indicator of the marginal resource cost of providing that energy. For example, electricity rates have traditionally been based on the average cost of electricity supply, rather than the (higher) cost of bringing on new capacity. Marginal resource costs, which may be higher or lower than retail prices, correspond to social costs.

Finally, the social discount rate reflects the social opportunity cost of capital and is generally lower than the private discount rate. In this analysis, an 8% social discount rate is used compared to a 12% private rate.

Implications of a Social Cost Perspective

Forests and Forest Management: Different discount rates and different energy prices will not affect all sectors to the same extent. Management measures related to forests and forest management, for example, will be only minimally affected because:

- a social discount rate of 8% rather than a private rate of 12% was used in the original calculations on the premise that the government would undertake most measures; and

- energy savings are only tangentially relevant in few measures.

Pulp and Paper: For the pulp and paper industry, a lower discount rate will enhance the attractiveness of measures by reducing the relative weight given to capital expenditures. However, energy prices net of taxes will be lower, thereby reducing the benefits of energy projects. The net impact will depend on the specifics of the measure. However, it is unlikely that the adjustments would contradict the general conclusion that there exists a pool of conservation projects that could reduce energy consumption by 18% over the next 15 years.

Transportation: However, adjustments to energy prices to account for differential tax structures are important in the transportation sector. The tax structures for each of the four primary fuel types are (B. Stipdonk, B.C. MEMPR, pers. comm.):

Fuel type	**Provincial Tax** (cents per litre)	**Federal Excise Tax** (cents per litre)
Gasoline	9.76	8.57
Diesel	10.20	4.00
Propane	-----	-----
Natural gas	-----	-----

Comparing retail and social cost prices for each fuel type:

	Retail Price	**Without Taxes**
Gasoline	$15.21	$ 9.93
Diesel	$12.42	$ 8.57
Propane	$ 4.51	$ 4.51
Natural gas	$ 7.62	$ 7.62.

Adjusting prices for these taxes does affect the relative attractiveness of different transportation measures, although the overall impacts are modest. For example, the cost-effectiveness of most measures is somewhat lower due to the lower value of energy savings. However, only one energy conservation measure shifts categories: the estimate for cost-effectiveness for public transportation falls from savings of about $10 per tonne to a slight cost of $6 per tonne.

Conversion of gasoline cars to propane remains cost-effective, although conversion to natural gas generates savings for commercial vehicles from a social cost perspective and diesel conversions become uneconomic for both private and commercial vehicles.

In the transportation sector, then, adjustments for a social discount rate and energy prices result in two adjustments to the list of most promising measures in Exhibit 9.1; namely, public transportation falls out of the group as does conversion of private vehicles to natural gas.

Residential: Changes in discount rates and energy prices have relatively complex implications for the residential sector. By itself, a lower discount rate increases the attractiveness of measures and generates net savings for some measures where costs are small.

Adjustments to energy prices to account for different resource costs are more complex and differ depending on the energy type, its application (e.g., space heating vs. water heating) and time frame. A comprehensive assessment of social costing is outside the scope of this study. However, rough adjustments based on the analysis in Marvin Shaffer (1991) provide some indication of differences in the social and commercial attractiveness of certain measures.

A sensitivity test was run using the prices noted below:

		Social price ($/GJ)[1]	Retail price ($/GJ)
Natural gas	space heat	3.218	4.664
	water heat	5.784	4.664
Electricity	space heat	9.130	15.475
	water heat	14.390	15.475

These adjustments, using a 8% discount rate, had only marginal effects on the cost-effectiveness estimates of the various measures. In terms of energy conservation measures, the adjustment to social prices reduced total energy savings; however, this impact is offset by a lower discount rate. The most significant changes occurred in electricity measures for space heating, where the conservation measures appear less attractive from a social than private perspective (i.e., the price effect outweighed the discount effect).

The cost-effectiveness of conversions from natural gas to electricity were also affected. The smaller price differential between social natural gas and electricity prices than between their respective retail prices reduces the costs involved in conversion and, therefore, enhances their attractiveness. This effect is compounded by the lower discount rate. However, conversion for both space and water heating remain costly, at about $30 to $60 per tonne CO_2.

Overall, the adjustments to social prices and discount rates do not affect the categorization of residential management measures presented in Exhibit 9.2. This conclusion holds even if electricity prices rise faster than natural gas prices, as suggested in the Shaffer report because the increase will simply make conversion measures even more costly than the private cost noted in Exhibit 9.2.[2]

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[1] To maintain consistency with the analyses done in previous sections, social prices were calculated by applying the ratio of retail to supply costs in Marvin Shaffer (1991; pages 19 and 47) to retail prices used in this analysis. Note: supply costs do not include factors for environmental costs.

[2] By the same reasoning, electricity conservation measures will be even more attractive than suggested in Exhibit 9.2, but this will not change set of most promising measures.

In summary, assessment of CO_2 management measures from a social perspective results in only two significant changes to the list of promising measures from a private cost perspective; namely, the removal of public transportation and conversions of private vehicles to natural gas.

9.3 Barriers to Implementation

In order to develop recommendations or even directions for management efforts, measures must be evaluated with respect to a number of factors, not just cost and abatement potential. Other factors could affect the actual rate of adoption of the measure and its effectiveness, or the government's ability to effect change. For example, inconvenience and/or enforcement may prevent implementation of desirable -- and even cost saving -- energy conservation measures.

Also, initial attitudes or alternative assessments of the measures by stakeholders could provide important context for any greenhouse gases management policies, especially where general measures are considered for very industry- and location-specific applications. Without consideration of these non-monetary issues, policy development could be jeopardized. It is also appropriate at this stage to assess the major uncertainties associated with various management measures.

In this section, possible barriers and extenuating factors are examined for each of the "promising" measures identified in Section 9.1 above and summarized in Exhibit 9.3. The discussion is based on the literature and communications with a variety of individuals in industry, government, and other organizations (e.g., environmental groups, university). Names of contacts are included in Appendix F. The number and seriousness of barriers to implementation are used to further refine the categorization of management measures in Section 9.3.

9.3.1 Forests and Forest Management

Planting NSR and Marginal Agricultural Land

Barriers and concerns regarding re/afforestation can be roughly divided into four groups:

Environmental Considerations

Environmental considerations relate to (i) the role of planting in reducing carbon dioxide levels; (ii) broader, non-greenhouse gas (GHG) ecological concerns; and (iii) wildlife concerns. Ecological drawbacks to planting depend on the nature of the planted stock and its management. Some U.S. documents indicate a concern that monoculture stands have lower resistance to pest infestations and can strain water resources (Lashof and Tirpak, 1990, pg.V-145).

The majority of hesitations and concerns relate to the effectiveness of planting as a CO_2 measure and the validity of the values presented in Section 3 of this report. Specifically, there is some concern that growth and survival rates of temperate forests may be compromised by climate change and air pollution.

Exhibit 9.3: Summary of Barriers to Implementation

Measure	Barrier							
					Environmental			
	Financial	Market / Product	Technical / Operational	Attitudinal	GHG	Non-GHG	Rate of implementation	Other
Forests and Forest Management								
Utilization of harvest residues & wastes	✔		✔		✔	✔		✔
Plant NSR agricultural land	✔				✔	✔		✔
Plant marginal agricultural land	✔				✔	✔		✔
Site treatment			✔		✔	✔		✔
Pulp & Paper								
General energy efficiency improvements	✔		✔	✔				
Further substitutional away from fossil fuels	✔		✔					
Process changes	✔	✔			✔	✔	✔	✔
Transportation								
Vehicle fuel efficiency		✔		✔	✔	✔	✔	✔
Driver training				✔			✔	✔
Route & traffic planning				✔	✔			✔
Vehicle maintenance			✔					
Conversion to natural gas		✔			✔	✔		
Conversion to propane		✔	✔		✔	✔		✔
Public transportation				✔				✔
Trip reduction measures			✔	✔			✔	
Land use						✔	✔	✔
Residential								
User education / practices				✔				
Passive solar	✔			✔			✔	✔

As recognized in Section 3 above, planting offers a one-shot benefit: an incremental amount of CO_2 would be absorbed by the growing forest, but once it reaches maturity, its CO_2 balance levels off with no net absorption *or* it enters a harvest/regeneration cycle with its own carbon cycle. In neither case are CO_2 absorption benefits continuous in the way that energy conservation technology in the residential sector could be. The value of the planting measure, then, must be viewed as a stop-gap, providing lead time to bring other, longer lasting measures on stream.

There remains doubt in some minds about absorptive capacity of planting NSR and marginal agricultural lands. The specifics are:

- the actual incremental biomass growth on NSR lands that are restocked vs. those on which natural regeneration is occurring;
- appropriateness of agricultural soils and general feasibility of developing stands on marginal agricultural lands (with respect to survival and growth rates); and
- uncertainty regarding the amount of land that is available and suitable for foresting.[3]

With respect to wildlife, afforestation will clearly alter the ecosystem in the planted areas. This in turn will alter biodiversity of the area, creating opportunities for some species but eliminating some existing habitats.

Disposition of Mature Forests

There are also some concerns regarding disposition of resulting stands and possible effects on timber/forest industry markets. There is no question that planting NSR and marginal agricultural lands will result in considerable areas of "new" forests. However, these stands pose no more threat to industry viability than the abundance of forest resources that has characterized the industry in B.C. for most of its existence. Indeed, the new stands may provide a less expensive source of fibre than less accessible areas currently being logged, increasing the potential margin for forest companies. Alternatively, the stands could relieve some of the pressure to preserve old growth stands that can support non-timber values such as recreational and environmental amenities.

Financial Barriers

As noted in Section 3, the absolute costs of restocking NSR and agricultural lands are considerable, totalling $530 - 765 in present value terms ($440 - 550 for NSR and $90 - 210 for marginal agricultural land). A federal/provincial program plant NSR lands, which has recently

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[3] This uncertainty is reflected in the two estimates presented in Exhibit 3.2. Further research is required to verify the reasonableness of either value.

begun its second five-year term, provides some of the needed funds. However, concern over the federal deficit and expenditure priorities at the Province will put a strain of funds available for replanting.

This strain will be even more pronounced for marginal agricultural lands as these areas are not included in the federal/provincial program. Furthermore, land costs which were not included in the estimates because of lack of data, or alternative compensation payments to the farmer/land owner will further test financial resources.

Other Considerations

There do not appear to be any serious barriers to planting from technical and institutional perspectives, except uncertainty about the role of the farmer/land owner of marginal agricultural lands and the types of institutional arrangements that could be designed to ensure adequate planting and management. The type of arrangement will have important implications for cost, tenure, disposition of the mature stand, and survival and growth rates of the seedlings. In addition, the process for identifying appropriate lands must be sensitive to the agricultural potential of each parcel and its role in the local supply of food and feed.

Utilization of Residues and Wastes

The CO_2 inventory used as a basis for this study clearly indicates the significant contributions of slash and wood residue burning to provincial totals. Utilization of the wastes is discussed in Section 3 (with respect to forests and forest management) and Section 4 (with respect to pulp and paper), and includes such uses as durable products or substitutes for fossil fuels. In this section, we will concentrate on product or export opportunities; use of waste for local cogeneration is discussed in the section on pulp and paper measures below.

Financial Viability

The barriers and questions regarding utilization of wastes are dominated by market and profitability factors. Although various reports suggest product and market opportunities do exist (e.g., exports as fuel pellets), industry representatives seriously question these conclusions. There are several factors that contribute to this doubt.

First, developing and marketing new products poses very significant risks which, in lean years, are not acceptable to forest companies or their shareholders. Second, high costs of removing or transporting wastes require significant value added benefits in manufacturing, benefits that are difficult to garner in the intense international competition that characterizes the forest industry. Third, the economic feasibility of many of the options are sensitive to international oil prices in two ways. The actual level of oil prices is critical to the price of any waste energy product (such as fuel pellets) and, therefore, to profitability. Volatility of international oil prices can also strain a product's viability because it increases risk and the acceptable level of return to investors.

Simply put, industry representatives question the existence of viable uses of harvest residues and waste wood.

Environmental Concerns

The ecological appropriateness of removing harvest residues has been questioned. The concerns relate to the preservation of forest nutrients to maintain soil fertility and protect wildlife and biodiversity. The loss of organic matter could be especially serious after the second or third forest crops. One industry representative indicated that environmental groups are in fact encouraging ("pressuring") logging operations to leave large organic debris in the forest.

A second environmental aspect concerns the amount of energy required for transporting residues and wastes and producing alternative products. In some of the examples in Section 3, energy differences have been taken into account; however, a more thorough analysis is needed to estimate differential CO_2 profiles on a cradle-to-grave basis.

While industry representatives that were contacted viewed reforestation of NSR lands as a "non-issue",[4] there was general support for afforestation of marginal agricultural lands.

Site Treatment

The main constraint in assessing site treatment methods is the lack of consensus on the carbon profiles of different treatment options. This research is further complicated by the multitude of site-specific factors that must be taken into account in any assessment. A corollary constraint is the professional time and expertise required to evaluate site treatment options for each site from a CO_2 perspective, although this may be somewhat mitigated by the planning process that is currently in place in the Province.

Other barriers include the consideration of other environmental criteria including pressure to leave (or not leave) logging debris in the forest for aesthetic, wildlife and nutrient preservation, and economic return to the producer (which fluctuates depending on market situations and prices for end products).

9.3.2 Pulp and Paper

The primary measures identified for the pulp and paper industry are general energy efficiency improvements, further substitution away from fossil fuels, and process changes (e.g., towards recycling and higher yield, e.g., mechanical). Barriers and influencing factors for each of these options are discussed below; however, two factors provide a critical backdrop to any evaluation of measures for the industry.

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[4] Reforestation of NSR lands was generally considered a non-issue because: (i) it does not lie within the responsibility of the private companies; and (ii) there is currently a mechanism in place (the federal/provincial agreement) to undertake reforestation.

First, the financial health of forest industries is currently very weak. Poor commodity prices have reduced margins and eliminated discretionary investment funds. Second, many representatives in the industry accord a relatively low priority to the CO_2 issue for financial reasons and because of the urgency of other environmental matters, in particular compliance with biological effluent treatment and AOX regulations and pending federal dioxin regulations.[5]

General Energy Efficiency Improvements

Financial factors dominate the barriers to energy efficiency measures. As indicated in previous sections, cost-effective investments do still exist; the financial barriers relate to the *level* of profitability. Under the current financial climate, extremely rapid paybacks (e.g., 6 months vs. 2-3 years) are required for investments, eliminating many energy projects.

Cash constraints and cost savings both feed into the problem. Cash constraints and the ability to raise funds for energy investments is symptomatic of the overall financial health of the industry and are further tightened by diversion of any funds to other environmental priorities or quality improvement. Furthermore, low energy prices have been the rule rather than the exception recently and have undermined the level of savings that are generated by energy projects.

Other concerns related to energy efficiency are operational: Introduction of new systems or technologies carry an inherent risk of increasing down time, increasing maintenance and operating costs, or threatening quality or unit costs. These risks increase the level of financial return required for the project and can, in some instances, present an absolute barrier to their introduction.

Further Substitution Away From Fossil Fuels

As discussed in Section 4, the pulp and paper industry has significantly decreased fossil fuel consumption over the last 17 years. This change has been promoted by increased use of waste fuels and electricity from the main grid (in the case of ground-wood mills). However, fossil fuel combustion in the industry still accounts for about 2.9 million tonnes CO_2 emissions per year, or about 3% of total provincial emissions. Increased use of waste fuels is technically feasible, but has the following problems.

Maximum use of waste fuels requires a combination of different equipment *and* systems modifications, modifications that may only be feasible in a major plant modernization program or new installation. Given the financial health and plant age structure of the industry, few such major projects are likely in the short to medium term.

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[5] The cost of compliance has been estimated at $1 -$1.2 billion over the next 3-4 years for dioxin/AOX alone (B. McCloy, COFI).

Where incremental increases in waste fuel use are possible (i.e., does not require major capital programs), other constraints arise, including:

- Technical constraints -- Operational problems have been associated with "difficult to burn" wood residues. Such wood residues include wastes that have high moisture contents, are mixed with sludges, sand and/or soil (e.g., waste from dryland sort yards) and otherwise have low Btu value. Breakthroughs in wood residue and sludge dewatering technologies could alleviate some of these constraints. Another technical barrier is limitations in highly efficient back pressure power generation due to limitations in process steam requirements.

- Financial -- As with general energy efficiency measures, any projects that require additional expenditures are currently under close scrutiny and face fairly high hurdle rates.[6] Factors that moderate the return from greater use of waste fuels include:

  - high capital costs;
  - low prices of traditional (fossil) fuels;
  - increased availability of natural gas; and
  - B.C. Hydro pricing and buy-back policies for cogenerated power.[7]

  In some instances, the excess steam cannot be fully used in the plant, which undermines the economics of burning waste woods if alternative uses cannot be found.

The rather low priority now placed on energy security also compromises the relative attractiveness of such projects.

The barriers to natural gas substitution have been primarily availability. However, with completion of the Vancouver Island pipeline, virtually all mills in the Province will have access. A second barrier to the use of natural gas underlies the EMPR energy forecasts for the industry. Specifically, heavy oil prices are expected to remain soft, so that mills are likely to use both fuels over time depending on relative spot prices of the two energy sources.

Process Changes

The pulp and paper industry in B.C. is dominated by kraft mills. As described in Section 4, kraft mills are significantly more energy - intensive than mechanical or recycle mills and generate more fuels in the form of black liquor. However, process change from kraft to

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[6] A hurdle rate is the rate of return required to justify an investment project. Hurdle rates tend to increase in recessionary times as cash constraints bind.

[7] Very recent changes in B.C. Hydro policies may mitigate this constraint. Further information will be included in the final report.

mechanical or other processes as a CO_2 management measure must be considered with several factors in mind.

First, these changes in process equipment represent very significant investments that approach the levels required for greenfield mills. In spite of the current age structure of kraft mills in the Province, many have completed modernizations so that write-off of recent investments is a barrier.

Second, process changes by definition change the final product. For example, recycled paper has lower strength and quality and different end-use characteristics than kraft papers. A significant move to different grade mechanical pulp products could increase world supply and depress prices for that quality grade. The decision to move to mechanical pulp or recycle, therefore, must take market factors into account.

Third, both mechanical and recycle mills require different raw material mixes than kraft. In the case of recycle, the availability of recyclable paper is limited in western Canada and the economics of hauling waste paper from the U.S. are poor. In fact, MacMillan Bloedel recently announced plans to build a recycle mill in the San Francisco Bay area. Although a recycle mill may use some virgin pulp from the Province, the transportation economics do not lie in B.C.'s favour. While some recycling opportunities do exist in B.C., the Province is not internationally competitive in recycled paper products as recycle paper tends to serve local markets. Instead, current competitive strategies focus on maximizing the quality of B.C. fibre by concentrating on high quality pulps and specialty papers -- products that can only be produced through the kraft process.

Fourth, there are broader environmental factors to consider. Although recycle and mechanical pulp consume less energy *at the mill*, there is considerably less confidence within the industry that recycled paper would be less energy-intensive after collection, sorting and transportation of waste paper are taken into account. This is an area for further research. Apart from differences in energy use, various processes have different environmental profiles. Effluent contaminant concentrations before treatment are typically higher for mechanical pulp mills when compared with a modern kraft process.[8] Impacts on receiving water will depend on treated effluent characteristics and degree of effluent closure, the latter currently more practical for mechanical pulp mills.

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[8] Comparative BOD and TSS levels before treatment are:

Process	BOD (kg/ADMT)	TSS (kg/ADMT)
Kraft	15-35	10
TMP/CTMP	30-140	10-20
Recycle	10-70	100-700

Source: H.A. Simons

9.3.3 Transportation

Vehicle Fuel Efficiency

The four primary barriers to increased fuel efficiencies are outlined below:

- A wide variety of factors are considered in the purchase of a car. In addition to fuel economy, buyers assess safety, comfort, performance, and cost. These factors can raise trade-offs with fuel efficiency. For example, weight reduction to improve fuel efficiency can compromise the structural strength of the vehicle and, consequently, its safety. Consumer preference for larger cars could also mitigate against increased fuel efficiency. The importance of fuel economy will be driven by the cost of fuel, as evidenced in the 1970's. With today's low energy prices and security of supply, fuel economy is not currently a dominant purchase factor.

- The vehicle market is becoming increasing global. The ability of one small jurisdiction such as B.C. to influence international car manufacturers to change car and engine design is severely limited. Hence, unilaterally legislating fuel efficiency standards could be impractical. Influence within B.C would be limited to encouraging consumer preferences for smaller, more fuel efficient models. Estimates of the quantitative contribution of these two sets of factors to improve efficiency are not available.

- Increasing fuel efficiency, by definition, lowers the cost of driving. Theoretically, lower costs may have two perverse effects on vehicle miles travelled (VMT): (i) people may simply drive more for pleasure or as a substitute for alternative modes of travel; and (ii) lower costs may encourage the trend towards light duty trucks which generally have lower fuel efficiency than automobiles.[9]

- Improving fuel efficiency through greater use of alternative materials such as composites, plastics, and other new materials may compromise the extent to which car components can be recycled, raising waste disposal issues (Lashof and Tirpak, 1990).

However, a number of factors suggests that these barriers to improved vehicle fuel efficiency may be manageable. For example, fuel efficiency standards are commonly understood and have generated a considerable body of knowledge and expertise which could be drawn upon. Also, there may be a willingness by consumers to pay for these modifications (Godding, 1990).

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[9] This effect is known to economists as the income effect: as a good becomes less expensive, consumers tend to use more of it. In this case, as the cost of driving falls (because of greater fuel efficiency), people will drive more.

Vehicle Maintenance

Like fuel efficiency standards, inspection and maintenance programs are familiar and have a history which can be used to design and implement the program. Similar initiatives in other jurisdictions can support public acceptance of the program. On the negative side, implementation of an I/M program will depend on the availability of trained staff and methods to ensure quality assurance. The GVRD, in association with the B.C. and federal ministries of the environment, have examined the feasibility of an I/M program and recommended its implementation for February 1992. The reader is referred to the report of the I/M Implementation Task Force (1989).

Public Transit and Driver Training

Increased use of public transit and driver training share the same primary obstacle to reduction effectiveness: motivation. In the case of increased use of public transit, the barriers are well known and include impingement on convenience, independence and flexibility. In a 1989 downtown work trip survey, the City of Vancouver found that almost half (43%) of drivers indicated and actually did require their vehicles during the work day, suggesting that the convenience-related barriers could be significant and that the effectiveness of incentives to promote transit (e.g., rideshare programs) may fall short of expectations.

The barriers to increased transit use could be more significant if strong measures were introduced over a short time period compared to a long phase-in period that would allow long term trends in demand and supply of transit and parking, as well as concepts such as rideshare programs, etc. to work their way through the economy.

Unless included as a requirement of attaining a driver's license or renewing car registration and insurance, the motivation for individuals to complete driver training courses is low mainly because the perceived energy savings are not significant. Restricting the education to only new drivers may have minimal effect on emissions, even over the long term. Alternatively, a general information campaign could be designed, although the effectiveness of such programs are extremely difficult to evaluate.

Route and Traffic Planning

Because route and traffic planning is a composite of a wide range of measures, the barriers to implementation are difficult to specify. However, major concerns include:

- the time frame over which traffic planning measures can be introduced, given tight municipal and provincial budgets and the logistical characteristics of some of the measures;

- required cooperation with municipalities (i.e., many of the measures may be outside the provincial government's jurisdiction); and

- some route planning measures require education of drivers and fleet operators and, therefore, have motivational problems similar to those issues discussed above for public transit.

Perhaps of most concern is the possible perverse impact that route and traffic planning could have on VMT. Put simply, if the measures do relieve congestion, driving could become more enjoyable (less stressful), more convenient and faster, thereby encouraging greater (not less) use of the automobile. Therefore, the application of route and traffic planning measures should be carefully evaluated. It may be the case that such measures are only appropriate outside central cores, in areas where transportation options are limited.

Conversion to Alternative Fuels

Perhaps the most significant concern regarding use of alternative fuels as a management measure for CO_2 (and other environmental problems) is the technical uncertainty surrounding their emissions performance. As noted earlier, a very wide range of estimates exist for emission factors and fuel efficiency. Technical uncertainty, then, presents a legitimate barrier to conversion to alternative transportation fuels.

Other barriers to further conversion of gasoline powered vehicles to natural gas (CNG) or propane are related to (i) performance; (ii) availability of supply; (iii) safety and environmental considerations.

Performance: CNG autos have only one-third the range of a gasoline powered car with the same sized fuel tank; larger fuel tanks would probably intrude into trunk space. For some light duty vehicle owners, this characteristic could eliminate it as a substitute fuel and is a major problem for most heavy duty vehicles. Because it has about 10% less power than gasoline or diesel-powered vehicles, CNG is most suitable for engines running at relatively low speeds and is not suitable for high power applications.

Range is not likely to be a significant barrier for propane since propane vehicles have a range about 75% that of conventional cars; taxi drivers find it preferable to CNG for this reason.

Availability: Natural gas is widely available in B.C. as a home and industrial fuel, so an extensive distribution infrastructure already exists and the fuel is known to the general public as an energy source. As a compressed gas usable for transportation, CNG is not nearly as widely available or well known. To outfit a commercial refuelling station with a CNG compressor would cost approximately $250,000 but would allow fast refuelling. Subsidies or forced markets may be required to persuade more station owners to provide CNG pumps. Alternatively, home compressors at a cost of $2,500 to $3,500 have just been approved by the B.C. Utilities Commission for local sale. These provide slow refuelling rates (hours to overnight) but are suitable for owners who can "plug in" every night (and who have garages for the pump location).

As a by-product of natural gas, propane is widely available already as a non-transportation fuel. For transportation use, it will require more refuelling stations within the City of Vancouver; otherwise, GVRD distribution is already quite good. Overall fuel availability, however, will limit propane use to about four to five times the number of vehicles now using it; thus its CO_2 abatement potential is modest. It also tends to be scarce and expensive in winter as propane is used for heating purposes; these supply problems have recently resulted in a diminishing number of fleet conversions.

Safety and Environmental Considerations: Spilled propane fuel (usually from poor conversions) will pool since it is heavier than air and can present a significant hazard of fire or explosion.

Air pollution emissions also differ among the different fuels, although the literature on potential ozone formation is not conclusive. In fact, the range from low to high estimates of NO_x/VOC emissions for the same fuel can differ by a factor of six (Concord Environmental, 1991, draft). The range reflects different operating conditions, technology configurations, ozone-producing relationships, and measurement techniques. Overall, the studies suggest that propane and CNG have the *potential* to reduce ozone levels through reduction of VOC's; but the impact on NO_x can vary considerably.

Land Use Planning

Although potentially a significant CO_2 management measure (see Section 5.2.3); land use planning measures for carbon dioxide management must take into account a vast array of other considerations. For example, privacy, aesthetics, green spaces, and crime levels must all be considered and weighed against high density planning models. Other environmental issues, such as waste management and concentration of air pollutants, will also affect the ability to reduce per capita carbon dioxide from the urban transportation sector. Finally, changes to zoning regulations to encourage mixed use development will only be gradually effective in reducing transportation emissions as land development follows is naturally slow path.

9.3.4 Residential Sector

Because there are a number of measures in the residential sector that are cost-effective, we begin with a general discussion of barriers to energy conservation in this sector. These barriers are applicable to the four promising residential barriers identified above.

General Efficiency Measures

Barriers to implementation of energy conserving measures in the residential sector are financial and institutional. The main financial barriers are based on the "lumpiness" of costs for these investments. Up-front capital costs have two impacts. First, individual homeowners, like corporations, are hesitant to undertake significant capital costs, even though the economics may be very attractive over the long term. This hesitation may be a response to uncertainty (e.g., they may not expect to stay in the house long enough to reap the benefits) and to restricted

budgets that increases the opportunity costs of funds above the internal rate of return for the investment.

Second, developers and builders are unlikely to be able to recoup additional high capital costs because of the plethora of factors that are considered when purchasing a house or apartment building.

Finally, several people felt that low energy prices have effectively increased the payback period for many energy projects.

A number of institutional factors can exacerbate these difficulties. First, neither homeowners or builders are very well-informed concerning energy saving measures and technologies or their benefits (H. Mohammed, EMR, pers.comm.). Second, the implementation of new energy saving technologies and measures is often dictated by the rate of turnover in the housing stock because many measures are less costly to install during construction than as a retrofit. However, artificially accelerating the rate of housing turnover would likely have costs that could not be justified by the energy savings.

Solar For Space Heating

Barriers to implementation of passive solar for space heating reflect many of the problems associated with general efficiency measures.

For example, solar practices generally require the home/building owner to make an *up-front capital investment*. In addition to the drawbacks mentioned above, solar has to compete with traditional LFO, electrical and natural gas options for which the capital charges (e.g., for pipelines, distribution systems) are included in fuel payments and, therefore, are spread out over many years and many users. In addition, the capital portion of the investment has to be financed in after-tax dollars at retail interest rates, as opposed to the wholesale rates that can be commanded by power utilities and companies (R. Kadulski, Solar Energy Society of Canada, pers.comm.).

In the case of passive solar, there is an additional cost that window manufacturers have to bear -- expenses of re-tooling in order to produce energy-efficient windows (S. Bolcso, EMR, pers.comm.).

Institutional obstacles for solar include the fact that many of the potential benefits of passive solar are generated by proper placing of windows. This measure, then, is restricted by the rate of housing turnover and the knowledge and attitudes of builders. Where builders use stock housing designs, the process has to step back even further to affect the attitudes and practices of architects.

There are also a number of educational and attitudinal obstacles to passive and direct solar. For example, consumers are not generally well informed about potential benefits, and the technologies that are available are not recognized (S.Bolcso, EMR, pers.comm.). There is also

a general resistance to change that is exacerbated in the solar case by negative perceptions about appearance and mechanical reliability.

User Education

Of the four "promising measures" for the residential sector, user education encounters the fewest barriers. There are, of course, questions as to the most effective vehicle for user education (e.g., television ads vs. literature etc.) but the primary challenge is to make people pay attention -- to motivate them to make small energy savings changes around the house. During the oil shocks, concerted efforts were made in the residential, commercial and industrial sectors alike to attend to those "housekeeping" measures. However, lower energy prices and security of supply have eliminated the strong incentive to conserve energy. In the absence of energy price increases, an alternative, widely accepted motive must be brought to bear.

9.4 Categorization of Management Measures

Exhibit 9.4 categorizes each of the promising measures according to: (i) abatement potential; (ii) cost-effectiveness; and (iii) barriers to implementation. The four categories are:

I. Measures that are commercially **economic** with **low barriers** to implementation. This category includes all measures for which cost savings/monetary benefits to society or the user exceed the cost (i.e., the cost-effectiveness value is zero or negative).

II. Measures that are commercially **economic** but have **high barriers** to implementation.

III. Measures that are **not economic** (i.e., costs outweigh benefits and cost savings) with **low barriers** to implementation.

IV. Measures that are **not economic** with **high barriers** to implementation.

V. Measures that are not yet technically proven.

As indicated, about half of the measures fall into the first category: economic with low barriers to implementation. An additional four measures are economic but face more serious barriers to implementation (Category II). With the exception of general efficiency measures and substitution to natural gas in the pulp and paper sector, the economic measures are dominated by management options in the residential and transportation sectors.

Categories II (economic, high barriers) and IV (not economic, high barriers) differ by more than their cost-effectiveness. The barriers inhibiting implementation of residential and transportation measures are generally related to attitudes and some technical difficulties. Barriers inhibiting pulp and paper and forest management measures, on the other hand, are more likely to require structural change in the forest industries and are less amenable to policy actions. For example, increased recycling would require considerable structural changes in the capital stock and

Exhibit 9.4: Categorization of Measures

	Abatement Potential*	Cost-effectiveness*	Barriers*	Category*	Timeframe*
Forests & Forest Management					
Utilization of harvest residues & wastes	H	M	H	IV	M-L
Plant NSR lands	H	M	L-M	III	S
Plant marginal agricultural land	H	M	M	III	S-M
Pulp and Paper					
General efficiency measures	H	H	L	I	S
Process changes	H	M	H	IV	M-L
Substitution to natural gas	M	H	L	I	S
Substitute to 100% self-generated fuels	H	M	M-H	IV	M-L
Transportation					
Driver training	M	H	L-M	I	M
Route & traffic planning	M	H	M	I	S-M
Vehicle maintenance	M	H	L	I	S
Conversion to natural gas	M	H	M	I	S-M
Conversion to propane	M	H	M-H	II	S-M
Public transportation	M	H	M-H	II	M
Trip reduction measures	M	H	M-H	II	S-M
Vehicle fuel efficiency	H	H	M	II	M
Residential					
User education / practices	M	H	L	I	S
Passive solar (space heating)	M	H	M	II	S-M

Source: Exhibit 9.1 and ARA Consulting Group

***Definitions:**

Timeframe:
- S: Short-term — within 5 years
- M: Medium-term — 5-10 years
- L: Long-term — after 5 years

Note: Refers to time at which measures begin to affect carbon dioxide emissions / fixation.

Abatement Potential:
- L: Low — <0.5% of 1989 provincial emissions
- M: Moderate — 0.5% to 2% of 1989 provincial emissions
- H: High — >2% of 1989 provincial emissions

Cost-effectiveness:
- L: Low — >$10 / tonne CO_2
- M: Moderate — 0-$10 / tonne CO_2
- H: High — <$0 / tonne CO_2

Barriers:
- L: Low
- M: Moderate
- H: High

Category:
- I Measures that are *cost-effective* (i.e. generate savings) with *low barriers* to implentation
- II Measures that are *cost-effective* with *high barriers* to implementation
- III Measures that have *marginal costs* with *low barriers* to implementation
- IV Measures that have *marginal costs* with *high barriers* to implementation

product mix of the pulp and paper industry, and may not be able to support levels of employment and income generation comparable to those in the kraft pulp industry today.

Category III includes re/afforestation measures. While some barriers exist (e.g., appropriate institutional arrangements with farmers), these actions will be costly. Depending on the level of CO_2 abatement desired, these options may be an important component to the overall CO_2 management strategy.

Exhibit 9.4 also suggests timeframes for the measures. The timeframe indicates when the measures are likely to come into play, based on the barriers to each measure and its economic attractiveness. As indicated, the majority of measures could contribute to CO_2 management with little delay. Specifically, five of the 16 measures could be implemented within the next five years with an additional six available in the short to medium term. These measures are fairly well distributed across all sectors reviewed in this report.

Measures that are longer term options coincide with those with high barriers to implementation; namely, process changes and substitution to 100% self-generated fuels in the pulp and paper industry and utilization of harvest residues and wood residues. Also in the longer term, measures such as electric cars and other alternatively fuelled vehicles, land use planning, and mechanical abatement technologies (e.g., variations of a scrubber concept) could be effective in managing carbon dioxide.

The timeframes in Exhibit 9.4 indicate when the measure is likely to be available (from technical, administrative, or institutional perspectives), not the timeframe over which full abatement potential is reached. This approach was selected because implementation of measures will be highly dependent on:

- scientific advances in the field of climate change;
- the public's understanding and appreciation of the implications of climate change; and
- availability of more specific knowledge and information on which to support management measures.

Perhaps the most critical factor in implementation is the manner in which the government advances these measures, a topic to which we now turn.

10.0 Policy Considerations

The previous sections of this report identify the most promising CO_2 management measures based on abatement potential and cost-effectiveness, taking into consideration other barriers and benefits of each measure. Until now, we have abstracted from the challenge of actually *implementing* those measures. We turn to this specific issue in this section.

Policy aspects of CO_2 management measures are considered at three levels. In Section 10.1, a brief overview of the array of feasible policy tools is presented. In Section 10.2, policy interventions are discussed in terms of the specific measures while Section 10.3 offers a summary. We do not develop a package of policies for each measure, nor do we provide recommendations on an overall policy approach; that exercise will be carried out by the Government at a later date, taking into account all greenhouse gas abatement strategies and other policy priorities and objectives. The purpose of Section 10 is simply to provide a *framework* for the government's strategy for global warming.

10.1 Overview of Policy Instruments[1]

Policy instruments to effect CO_2 management measures can be grouped into seven categories:

- Research, Development and Demonstration;
- Information;
- Regulations;
- Financial incentives;
- Taxes;
- Marketable permits; and
- Direct government action.

Each of these policy instruments is briefly described below. The particular usefulness and advantages and disadvantages of each of the instruments is also discussed.

Research, Development and Demonstration

Research, development and demonstration (RD&D) is applicable to many of the management measures under consideration. Interestingly, for each of these management measures, government (either federal or provincial or both) is already supporting RD&D at some level.

[1] This section draws heavily on two documents: Office of Technology Assessment (1991) and United States Department of Energy (1989). Although the policy discussions do not present radical approaches or new thinking, they do offer comprehensive and highly relevant syntheses of policy considerations for global warming.

The policy instrument, therefore, is for government to increase this level of support in order to speed up the process of testing and commercialization.

RD&D requirements for a CO_2 management strategy covers a number of different factors, including:

- carbon balance of the measure itself;
- technical aspects of some measures (e.g., to solve operational difficulties);
- environmental trade-offs introduced by the measure(s); and
- demonstrations of measures as a mechanism to transfer technology and enhance the knowledge base for decision-makers.

In most of the examples discussed in Section 10.2., the RD&D activity is closer to the research end of the scale than the demonstration end. The rationale for government support, therefore, is that the private sector on its own will generally undertake less research than is desirable from a society-wide perspective. (This is because it is difficult, if not impossible, for an individual or firm undertaking research to appropriate the full benefits and to exclude others from using the knowledge derived from the research.) The rationale for increased support would be that, because of the recent recognition of the real potential for GHG-induced climate change, the RD&D now has a higher value for society as a whole than it did previously.

Information

Information programs are based on the assumption that if decision-makers are better informed, they will make better decisions. The most common goal of the kinds of information programs discussed in Section 10.2 is to stimulate decision-makers to opt for least cost "life-cycle" savings, as opposed to initial-purchase savings, in their energy decisions.

The main types of information programs that are applicable to the measures being considered are education and advertising. Moral suasion, an adversarial information policy by which the government attempts to persuade a firm to do something under the veiled threat of retaliation if it does not comply, has not been considered because it is unsatisfactory as a long-term policy.

In the context of a CO_2 strategy, there are a number of cases where the technology is proven and economic but not implemented due to lack of awareness of both the technical "fix" *and* the environmental impact of traditional practices/technologies. Therefore, the most common information measures for CO_2 will cover:

1) the magnitude of CO_2 current emissions and the contribution of prevailing activities and technologies to carbon dioxide emissions; and

2) the availability, performance and benefits of new technologies and practices.

Financial Incentives

In this category we include grants and subsidies, low-cost loans, and tax incentives. These instruments are a straightforward way of lowering the private costs of implementing various measures in cases where the public benefits exceed the private benefits and mitigating the up-front capital cost barriers to many measures. In Section 10.2, we generally use the umbrella term "financial incentive" because differences in these instruments are largely cosmetic. For example, one might choose grants as opposed to tax incentives if the barrier to implementation is high up-front cost, or one might choose tax incentives as opposed to low-cost loans because of greater ease of implementation, but these instruments all essentially amount to the same thing.

Taxes

The three main types of taxes considered are: (1) a general energy tax, (2) an emissions tax, and (3) initial purchase taxes. Both of the first two would be taxes on fuels and serve to increase the effective price of energy.

A general energy tax would be levied on the energy content of fuels. It would apply pressure to reduce total energy use, regardless of the source of the energy or its carbon content. An initial purchase tax would be levied on energy-consuming technologies and products and would have a similar effect as the general energy tax (i.e., reduce total energy use, regardless of the fuel type or its carbon content). Initial purchase taxes are useful in cases where it is known that consumers are more concerned with the initial cost of the product than with life-cycle costs.

Emission taxes attempt to directly tax the emissions of (in this case) CO_2. Such taxes are theoretically attractive because they can be set to fully internalize negative environmental externalities. However, they have two main drawbacks. First, they can be perceived as purchasable "licenses to pollute". Second, they require a large amount of information for their implementation. This information would have to be extremely disaggregated for CO_2 management -- essentially to each individual source of CO_2. For example, not all gasoline vehicles have the same CO_2 emission rate: some cars that are energy efficient would have lower rates than older, less efficient vehicles. Emissions taxes would require measurements of the actual emissions from each car.

To avoid these informational difficulties, a proxy emission tax -- the carbon tax -- could be set to reflect differing carbon contents of various fuel types and, by corollary, differing CO_2 emissions. A carbon tax would stimulate energy conservation and efficiency in the same way as a general energy tax but, in addition, would shift consumers from high to low carbon-emitting fuels. Carbon taxes have been discussed extensively in the global change literature.

Regulations

The two main types of regulations that are considered are controls and standards. The main control instrument applicable to the measures listed above would be emissions controls -- limits on the quantity or concentration of CO_2 that specific activities are permitted to discharge. The

standards that are considered include emission standards (e.g., standards for energy efficiency for new furnaces) and building codes.

The effectiveness of regulatory programs, particularly controls, may depend heavily on the quality of information available to the regulator. In this regard emissions controls are similar to emissions taxes (discussed above), could be administratively costly and inflexible, and may be economically inefficient (see discussion on marketable permits). Furthermore, standards that dictate the technological means to achieve environmental ends may hinder abatement research and development of new technologies.

The administrative and monitoring difficulties of regulation are exacerbated by the number and diversity of CO_2 sources. While a good portion of emissions are associated with pulp and paper, the majority of sources are much smaller and are highly decentralized (e.g., homes and buildings, motor vehicles, and small industrial establishments). To determine appropriate emission levels for each source, let alone monitoring and enforcing emission limits, would require enormous amounts of information and staff effort. Limiting regulations to the large point sources only could raise concerns of equity, could distort investment decisions in favour of unregulated sources and, unless accompanied by alternative measures for small sources, could seriously undermine the effectiveness of a provincial CO_2 management strategy.

Marketable Permits

Marketable permits for carbon dioxide, the "package" of greenhouse gases, or other pollutant have been widely discussed. Under a marketable permit system, policy makers fix the amount of carbon that can be emitted. The government then issues the allowed number of permits to emit the fixed amount of carbon to energy users. (The system could also be based on the distribution of permits to energy producers, but such a system would be somewhat more complex because of the need to deal with imports and exports.) Permits can be bought and sold by energy users just like fuels.

If the demand for energy rises, and, consequently, the total amount of energy produced increases, then emissions per unit of energy have to be lowered in order to not exceed the total allowable limit. Some holders of permits will be able to lower emissions more easily (i.e., less expensively) than other permit holders, and they can then sell their permits (at a profit), to the others. The price of marketable permits will be set by the abatement cost structures throughout the trading area. Thus, in this system not every energy user is forced to lower emissions by the same amount per unit of energy, and the system is, therefore, more economically efficient than across-the-board emissions controls.

The main potential benefits from marketable permit systems are generally seen to be[2]:

1) The costs of lowering emissions will distributed between firms in the market in a more efficient way, lowering overall industry costs.

2) Firms at the forefront of pollutant control procedures will be able to recover part of their associated costs by selling pollution credits earned by overcompliance, and they will be encouraged to proceed further with pollution control technology.

3) Firms are more favourably inclined to this market-based form of regulation (and, presumably, as a result would comply with it more readily).

4) Program administrative costs are reduced to the extent that the emission control decisions of each company are made internally on the basis of least cost. Some monitoring and enforcement costs will be incurred but are likely to be lower than a regulatory approach.

5) Such a system allows for entry/exit and expansion/contraction of firms in an area, and is therefore superior to a system that establishes an absolute prohibition on increased emissions by any new or existing firm. A permits systems may also be equitable in that a new plant/company can purchase a permit on a freely operating market, rather than having to comply with New Source Performance Standards (NSPS) that are set for new entrants and are generally higher than for existing plants.

Some of the difficulties with a marketable permits systems arise from:

1) The possibility that a small group of sources could effectively control the market for permits to (i) depress trades and the price of the permits, thereby compromising overall abatement effectiveness and (ii) create barriers to new entrants.

2) Monitoring and enforcement requirements. Although a permits system will allow sources to determine the level of emissions that minimizes their costs, some monitoring and enforcement will be necessary to ensure that emissions are no higher than the permitted amount.

3) Debate over the appropriate method of distributing the initial allocation of permits. Auctioning initial permits would impose an unwanted and possibly significant lump sum tax on current sources while grandfathering permits (i.e., distributing free of charge to existing source) may be viewed as inequitable because it effectively represents a gift of wealth or "reward" to current sources equal to the resale value of the permits.

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[2] Tietenberg, T.H., 1985, Emission Trading - An Exercise in Reforming Pollution Policy, Resources for the Future, Washington, D.C.

4) Difficulties defining the most appropriate parameters for the market with respect to geographic boundaries (especially where environmental impacts differ regionally), institutional arrangements for administering the permit system, and provisions for higher/lower permit levels.

The new Clean Air Act in the United States identified marketable permits as a policy instrument for sulphur dioxide emissions and CFC emissions and the Canadian Green Plan calls for a review of the appropriateness of economic incentives and their potential applicability to various pollutants.

In the context of CO_2, marketable permits have a number of practical benefits and challenges. On the benefits side, the analysis presented in the first part of this report clearly indicates that the cost of reducing CO_2 emissions varies considerably both within and across sectors. Because a tradable permits system is likely to yield the greatest cost savings (over a regulatory approach) where cost differentials are significant, application to the CO_2 issue may offer considerable benefits in terms of economic efficiency.

A permits system for CO_2 would also differ from actual experience with lead and sulphur dioxide in that carbon dioxides are emitted from a vast number of heterogeneous sources in a wide range of economic sectors. Sources include stationary point sources, mobile point sources, and area sources. This characteristic could mitigate the danger of market power becoming concentrated in a small number of sources, but complicates administration of the system from both an initial allocation perspective and for monitoring and enforcement.

One of the first tasks in developing a tradable permits system for CO_2 would be to choose the appropriate level of market -- primary producers of fuels (and fuel imports), industry and users where the fuel is combusted, or end users (i.e, where the energy service is actually consumed (Smith, 1991). Advantages and disadvantages lie with each level.

The diverse number of sources may also complicate institutional arrangements for tradable permits and could delay the time period over which the system becomes effective and/or functioning (e.g., a market that includes a large of players will likely take a longer time to reach equilibrium because information will not be easily transmitted and buyers and sellers will at least initially have few mechanisms through which they can assess supply and demand conditions and, hence, the appropriate price for permits.

Other considerations specific to marketable permits for greenhouse gases include:

- the role of other greenhouse gases;
- the availability and reliability of baseline data by which to set permit levels, especially if permits are to be grandfathered in;
- the effectiveness of permits for enhancing carbon sinks; and
- complexities in making changes to the aggregate level of emissions.

Direct Government Action

There are some possible management measures for which the most effective policy instrument may be simply for the government itself to undertake a certain action. Government action could take several forms but can be broadly divided into two groups: changes in planning or project evaluation criteria and direct investment in infrastructure/training/etc. Examples of direct government action include:

- measures to improve traffic flow, such as synchronized stop lights to maintain speeds in a way that will increase energy efficiency;
- the conversion of government vehicle fleets to alternative fuels, such as is being done in California; or
- introduction of carbon dioxide considerations in developing and/or evaluating site preparation plans.

10.2 Application to CO_2 Management Measures

The above list of available policy instruments suggests that the government has considerable flexibility in implementing CO_2 management measures. However, the applicability and appropriateness of specific policy instruments vary across sectors and management measures. In this section, policy opportunities are assessed with respect to specific sectoral conditions and barriers to implementation.

Before proceeding to policy options for specific measures, we explore policy tools that address the most common barriers and can be implemented across a number of sectors.

10.2.1 Policies for Major Barriers to Implementation

The main barriers to implementation of the promising measures and their frequency are:

- Financial (7 measures)
- Market/product concerns (4 measures)
- Technical/operational concerns (7 measures)
- Attitudinal/informational (8 measures)
- Environmental (9 measures related to greenhouse gases; 9 measures related to broader issues)
- Rate of implementation (6 measures)
- Other (12 measures).

Financial Constraints

Financial barriers are one of the most common barriers to the implementation of management measures, and one of the most serious. As noted in Section 9, financial barriers do not always relate simply to pay-back, but also to the "lumpiness" of costs and availability of cash. These barriers can be mitigated by either:

(i) increasing the cost of energy and carbon fuels in particular or other sources of emissions (e.g., wood residue burning); and/or

(ii) decreasing the cost of a more CO_2-benign alternative.

Both options increase the attractiveness of a carbon management measure.

The most obvious policy tools for affecting the financial attractiveness of a measure are taxes and financial incentives. The broadest policies are energy or carbon taxes, or emission fees. As noted above, taxes raise the cost of energy thereby improving the return to energy-conserving measures. For example, higher energy taxes could lower the pay-back for general efficiency measures in the pulp and paper industry to an acceptable level.

Permits and regulations could also increase the returns to energy/carbon saving measures: they would effectively increase the cost of emitting carbon dioxide because they would have a market value (in the case of permits) or would necessitate measures to reduce emissions (in the case of regulations), the least costly of which could be the measure in question. For example, a pulp and paper mill may be considering increasing the amount of energy used from self-generated (waste) fuels instead of oil. The economics of the switch would improve if the mill could earn cash for the change -- cash earned from the sale of carbon dioxide permits that they would no longer need. The sale of permits in this example has the added benefit that it would provide up-front cash to alleviate financing constraints.

On the other side of the coin, financial incentives could improve the attractiveness of an alternative practise or energy source. For example, low cost loans could reduce the capital cost barrier to passive and direct solar investments. Tax incentives, low cost loans, or direct payments differ in their particular characteristics and the appropriateness of the specific policy would depend on ease of administration, coincidence with the specific financial barrier and distributional requirements. For example, direct payments for driver training courses could be administratively difficult to monitor whereas tax break may be easier to monitor and have better distributional impacts.

In summary, financial barriers to implementation can best be addressed by increasing the economic attractiveness of the measure. The most widely applicable policies are general increases in energy prices through an energy tax, carbon tax, or marketable permits. Such policies, applied across the economy, would enhance the incentive to undertake carbon-saving measures. Financial incentives have the same impact, but are not as broadly applicable and should be matched to the specific measure/industry in question.

Market/Product Barriers - Technical/Operational Barriers

Research, development and demonstration are the primary policy tools for mitigating market or technical problems. For example, increased research into burn characteristics of "difficult" wood residues and modifications to current boiler configurations could increase the ability of pulp and paper companies to use more self-generated fuels, as well as enhance the attractiveness

of hog fuel fired district heating systems. On the product side, fairly detailed studies may be required to identify and adequately flesh out product opportunities for harvest residues and wood residues. These studies would address some of the risk currently associated with these ventures.

RD&D will have to be supported by adequate communications policies (to transfer new information to key decision-makers) and probably serves as a complement to other policies (e.g., financial incentives).

Attitudinal and Information Barriers

Attitudinal barriers can be mitigated by providing accurate information either through specific demonstration projects, or broad-based public education and advertising campaigns. For example, residential energy use practices could be encouraged through an advertising campaign relating energy consumption to environmental impacts, in much the same way as B.C. Transit is currently encouraging greater bus and LRT use. Direct government action plays a useful role as vehicles for demonstration projects (e.g., alternative fuel vehicles, passive solar space heating).

In some cases, very specific information may be the most useful. For example, general energy conservation measures and practices in the residential sector could be significantly enhanced by in-home energy audits. And in most cases, the effectiveness of informational policies would be enhanced by improvements in the economic attractiveness of the measure.

Environmental Concerns

Environmental concerns identified in Section 9.2 include both known environmental impacts (e.g., formaldehyde emissions from CNG) and environmental uncertainties need to be resolved before policies are introduced. Uncertainties naturally lead to RD&D policies, although in the environmental instance, RD&D refers primarily to basic environmental research related to (for example) the impacts of slash burning on forest productivity, full cycle assessment of the energy requirements of recycled paper, or the factors affecting emissions of ozone precursors in alternative transportation fuels.

Where environmental impacts are understood, the measure may be attractive from the perspective of GHG, but not from a broader environmental perspective. In these cases,a policy judgement must be made as to the relative importance of the various environmental concerns. Should the CO_2 priority dominate, mitigation measures should be explored and the measure adjusted accordingly. Indeed, some version of an environmental impact assessment as part of policy development may be warranted.

Rate of Implementation

A number of measures discussed in previous sections have a relatively fixed rate of implementation. Process changes in the pulp and paper industry will likely only occur within the existing cycle of investment in modernization or new plants; land use measures also must

work within the relatively slow process of urban planning and infrastructure investments. Policy tools to affect these rates are relatively limited.

However, implementation of other measures could be accelerated through increased knowledge of the decision-makers and the economics of change. For example, many energy saving measures in the residential sector are dependent on the decision of builders and architects. Campaigns directed at changing stock building designs could accelerate the rate at which new houses maximize the potential for passive solar space heating.

10.2.2 Policies for Specific Measures

Implementation of many of the measures identified in Section 9 would be encouraged by the policies affecting the general barriers to implementation discussed above. However, specific measures also call for specific policies, policies that fall outside the general approaches discussed above, or represent versions adapted for specific circumstances and pressures. These specific policies are discussed in Appendix E. and summarized in Exhibit 10.1.

10.3 Towards a Management Strategy

The scope of this study is limited to the identification of possible policy tools; the Terms of Reference do not extend to development of a *policy strategy*. However, it is appropriate to outline some of the subsequent steps in creating a strategy that have developed from this study.

First, the policy *tools* themselves should be assessed according to a set of criteria in much the same manner as this study evaluated management measures with respect to abatement potential, cost-effectiveness, barriers to implementation and timeframe. Relevant criteria for assessment of policy tools may include:

- flexibility;
- effectiveness in managing CO_2;
- practicality and desirability of setting CO_2 abatement targets for each policy;
- ability to monitor progress towards target reductions and to evaluate policy effectiveness;
- information needs;
- administrative requirements; and
- distributional and equity considerations.

Second, complementarities, synergisms and conflicts among policy tools (and measures) should be addressed. In the transportation sector, for example, there is a trade-off between reducing emissions by facilitating traffic flows and discouraging driving. A policy strategy must identify appropriate roles/applications for potentially conflicting measures.

Third, the discussion of barriers to implementation (Section 9.2) highlighted possible unintended impacts of CO_2 management measures. Before any policy is introduced, a review of its potential impacts (positive and negative; intended and unintended) should be undertaken with respect to

Exhibit 10.1: Policy Instruments to Implement Promising CO_2 Management Measures

	R/D &D	Information			Regulations		Financial Incentives			Taxes and Fees			Market-able Permits	Direct Gov't Action	
		Labels / Rating	Audits	Public Education	Perform-ance Standards	Building Codes	Tax Incentive	Low Cost Loans	Direct Payments	Energy Tax	Carbon Tax	Other Tax		Planning	Investment
Forests & Forest Management															
Utilization of harvest residues & wastes	✔						✔				✔		?	✔	
Plant NSR lands	✔			✔			✔		✔				?		✔
Plant marg. agricultural lands	✔			✔			✔		✔				?		✔
Site treatment	✔										✔		?	✔	
Pulp & Paper															
General efficiency measures	✔	✔	✔	✔	✔		✔			✔	✔		✔		
Process changes	✔						✔	✔		✔	✔		✔		
Substitute to 100% self-generated fuels	✔						✔	✔		✔	✔		✔	✔	✔
Substitution to natural gas							✔	✔			✔		✔		
Transportation															
Vehicle fuel efficiency	✔	✔			✔					✔	✔	✔	✔	✔	
Driver training				✔			✔		✔	✔	✔		✔		
Route & traffic planning	✔			✔						✔	✔		✔		✔
Vehicle maintenance					✔					✔	✔		✔		✔
Conversion to natural gas	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Conversion to propane	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Public transportation				4			✔			✔	✔	✔	✔		✔
Land use planning					✔	✔	✔					✔		✔	
Residential															
User education / practices			✔	✔			✔			✔	✔		✔		
Passive solar	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔		✔		✔

macroeconomic factors (such as international competitiveness and trade agreements) and other environmental resources. Such a review would offer a comprehensive assessment of the policy, it advantages and disadvantages, and suggest areas where mitigative measures may be needed.

Fourth, the appropriate strategy for carbon dioxide may not coincide with the most appropriate response strategy for global warming. As clearly recognized by the Greenhouse Gases Project staff, a comprehensive strategy can only be developed when possible management measures for all greenhouse gases are assessed and compared. This task now falls to the Greenhouse Gases Project staff.

Finally, the suggested measures and policy tools have been developed based on general literature. Where possible, representatives from industry, academia, and government were contacted and factors specific to B.C. incorporated. However, extensive consultations with stakeholders lies outside the scope of this study and, as such, this report may not adequately reflect the full spectrum of possible barriers or the complexities of possible impacts of different measures and policy tools. A final policy strategy could benefit from greater participation of individuals from industry, other government departments and academia.

APPENDIX A

DETAILED WORKING TABLES FOR ABATEMENT POTENTIAL AND COST-EFFECTIVENESS

APPENDIX A

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A. FORESTS AND FOREST MANAGEMENT MEASURES

A.1 Alternative Site Treatment

Impact on CO_2 abatement cannot be generalized across sites.

A.2 Increased and Utilization of Harvest Wastes

a) Abatement potential:

PWASTE	* RESAVAIL	*	CO_2 FACTOR	=kt CO_2 per year
10%	* 11.268 x $10^6 m^3$	*	1.96 t CO_2/m^3	=2210 kt CO_2/year

Where:

Name	Explanation	Source
PWASTE	Proportion of harvest residues that could be utilized	Assumption
RESAVAIL	Residues available from marginal small trees and wood from waste and breakage (based on AAC of 75 millon m^3; Crown Lands only)	Nawitka (1990)
CO_2 FACTOR	CO_2 emission factor for prescribed burning	B.H. Levelton (1990)

Note: Abatement potential assumes that final products are durable.

b) Costs

No detailed economic analysis of resulting products. Qualitative assessment taken from Nawitka Resource Consultants (1990).

Conclusion: Profitability varies depending on location and product. Small log sawmilling appears "feasible" (i.e., "at current product price with maximum wood, labour and utilities costs"). Most opportunties are classified as "possible", defined as "need product price increase, lower or incentive costs, or moderate combination of both".

c) Cost-Effectiveness

Not available. Expect some viability.

A.3 Whole Tree Chipping

a) Abatement Potential

PREDR	*	PBEMISSIONS	=	kt CO_2 per year
20%	*	13,065 kt	=	2610 kt CO_2 per year

Where:

PREDR	Percent reduction in harvest residues	Assumption
PBEMISSIONS	CO_2 emissions from silviculture-related prescribed burning	Appendix B

b) Costs

Not profitable in British Columbia (Bland, 1991).

c) Cost-Effectiveness

> $0 per tonne

A.4 Human-Caused Forest Fires

a) Abatement Potential

PRED	*	PHUMAN	*	CO_2 FIRE	=	kt CO_2 per year
25%	*	50%	*	4300 kt	=	540 kt CO_2 per year

Where:

PRED	Percent reduction in human-caused forest fire	Assumption
PHUMAN	Proportion of forest fires attributable to human causes	R. Clevette, pers. comm.
CO_2 FIRE	CO_2 emissions from forest fires	Appendix B

b) Costs

Costs would include advertising, public education and prevention. No estmate available.

c) Cost-Effectiveness

> $0 per tonne

A.5 Plant NSR Lands

a) Abatement potential

HECTARES	* AVGROWTH	* CBIOMASS	* EXPANSION	* CO_2FACTORS	=	CO_2 kt per year
553,145 ha.	* 2.25 m^3/ha/yr	* .455 t/m^3	* 2.5 to 3.2	* .45 $\frac{kgC}{kg.b.}$ * 3.7	=	2360 to 3020 kt CO_2 per year

Where:

HECTARES	Hectares classified as good and medium sites in NSR inventory	BC Forest Service (1988)
AVGROWTH	Weighted average growth rate for bolewood and bark for immature interior forest types	based on B.H. Levelton (1990)
CBIOMASS	Conversion of annual increment to weight	B.H. Levelton (1990)
EXPANSION	Expansion factors for biomass (proportion of total biomass to bolewood)	see note below
CO_2 FACTORS	(i) Proportion of carbon to biomass (kgC/kg.b.); and (ii) conversion of carbon to CO_2	B.H. Levelton (1990)

b) Costs

HECTARES	* COST	=	$
553,145 ha	* $795-995/ha	=	$440-550 million

Where:

COST	Planting costs per hectare as follows: planting: $434/ha seedlings: $300/ha ($.25*1200/ha)	clearing: $260/ha

c) **Cost-effectiveness**

(i) Total CO_2 fixation

2360 to 3020 kt CO_2 per year * 80 years = 188,800 to 241, 600 kt CO_2

(ii) Cost-effectiveness

$440 to 550 million -:- 188,800 to 241, 370 kt = $1.80 to $2.90/t

NOTES:

(i) Carbon fixation

There is considerable debate surrounding appropriate expansion factors, resulting in a wide range of estimates for carbon uptake rates (see table over). The variation is attributable to a number of factors, including:

- climatic conditions that affect growth rates;
- treatment of below-ground carbon uptake;
- species mix; and
- age structure of forest stand.

Another element of uncertainty in these rates is the extent to which forest biomass (and in particular, soil and forest floor biomass) is the result of new plantings or leftover debris from the previous forest stand.

Much needed research is underway in this field. For the purposes of this study, we have used a range of expansion factors: 2.5 and 3.2. The first figure is based on discussions with staff at the B.C. Ministry of Forests (D.Spittlehouse, pers. comm.). The higher value is based on figures used in the 1990 CO_2 inventory (B.H. Levelton, 1990); specifically, it is averaged over the 2.3 and 3.6 figures for mature and immature stands and adjusted upwards (by 1.2) to account for below-ground carbon uptake (OTA, 1991).

Examples of carbon uptake rate assumed in various studies (Tons per acre)

Other studies cited by B.H. Levelton (1990)	< 0.31
B.H. Levelton (1990--mature stands)	0.31
Braine & Rose, (ICF Report for EPA 1989, low est.)	0.35
This study (low estimate)	0.52
JBS Energy Inc. for California Energy Commission (1990)	0.60
This study (high estimate)	0.66
B.H. Levelton (1990--in mature stands)	0.74
Sanghi & Micheal (1991)	0.95
Buchanan (1989)	1.14
Chernick & Caverhill (1989)	1.40
Krause & Koomey (1989)	1.60
ICF Resources Inc. (1990)	1.81
Reichmuth & Robinson (1989)	2.07
EPA Policy Options (1989)	2.20
Moulton & Richards (1990)	2.50
Dudek & LeBlanc (1990)	2.70
Sedjo and Solomon (1988)	2.73
Braine & Rose, (ICF Report for EPA 1989, high est.)	6.60

Source: Sanghi & Michael (1991)

ii) Planting costs

Sanghi & Michael (1991) review of costs for reforestation:

Minimum	US $93/acre	=	Cdn $275/ha*
"Best Estimate"	US $275/acre	=	Cdn $815/ha
Maximum	US $403/acre	=	Cdn $1,195/ha

US Forest Service (1990) cost of treatment:

Pacific-Forest-Planting	US $247/a	=	Cdn $732/ha*

(* assumes exchange rate of US $1 = Cdn $1.20)

Cost estimates from B.C. Ministry of Forests totalling $795-995/ha are consistent with both sources.

A.6 Plant Marginal Agricultural Lands

a) Abatement potential

HECTARES	*	GROWTH	*	CBIOMASS	*	EXPANSION	*	CO_2FACTORS	=	kt CO_2 per year
132,750(315,305) ha.	*	3.0 m^3/ha	*	.455 t/m^3	*	2.5 to 3.2	*	.45 * 3.7	=	750-965 kt CO_2/year (1,790-2,290 kt CO_2/year)

Where:

HECTARES	No. of hectares in the Agricultural Land Reserve (ALR) in class 5,6 and 7 planted in forages, grains or horticulture. The figure in parenthesis also includes 50% of land in classes 5-7 in grassland and pasture.	B.C. Ministry of Forests (1980) B. Smith, Agriculture Land Commission, pers. comm.
GROWTH	Annual increment for aspen (interior)	B.H. Levelton (1990)
CBIOMASS	Conversion of annual increment to weight	B.H. Levelton (1990)
EXPANSION	Expansion factors for biomass	see A.5 above
CO_2FACTORS	Conversion of biomass to (i) carbon & (ii) CO_2 equivalents	(i) B.H. Levelton (1990) (ii) OTA (1991)

b) Costs

HECTARES	*	COST	=	$
132,750 (315,305) ha	*	$679/ha	=	$90 ($214) million

Where:

COST	Planting costs per hectare planting: $379/ha seedlings: $300/ha clearing: 0	R. Brown, B.C. Ministry of Forests, pers. comm.

Note: $379/ha represents the low end of the range of planting costs. This figure was chosen because access is assumed to be good, with low operating costs and high labour productivity.

Note: Excludes land costs.

c) Cost-effectiveness

(i) Total CO_2 fixation

[750-965 kt/year * 80 years] = 60,000-77,200 kt CO_2

with grassland: [1790-2290 kt/year * 80 years] = 143,200-183,200 kt CO_2

(ii) Cost-effectiveness

$90 million -:- 60,000-77,200 kt = $1.18 to $1.50 per tonne

A.7 Plant Specific Locations

a) Abatement potential

TREES	*	[(DENSITY	*	GROWTH	*	CBIOMASS	*	FACTORS
600,000 trees	*	[(0.01 ha/tree	*	2.0 m^3/ha	*	.437 t/m^3	*	3.33 to 4.66)
+ (ELSAVE	*	GJ/000 kwh	*	CO_2 FACTOR)]				
(400 kwh/tree	*	3.6 GJ/000 kwh	*	0.123 t/GJ)]				

= kt CO_2 per year

= 125-130 kt CO_2 per year

Where:

TREES	Number of trees planted in urban environments [U.S. program of 100 million trees; pro-rated for population is 1.2 million trees; ARA has taken 50% of 1.2 million trees]	ARA Group based on Lashof & Tirpak (1990) pg V-140.
DENSE	No. of trees per hectare (Spaced every 10 m or 100 trees/ha)	Assumption
GROWTH	Growth rate for immature fir trees (interior)	B.H. Levelton (1990)
CBIOMASS	Conversion of annual growth to weight for fir	B.H. Levelton (1990)
FACTORS	Expansion and conversion factors	see note below
ELSAVE	Electricity savings	Lashof & Tirpak (1990)
CO_2FACTOR	Weighted average CO_2 emission factor for residential	ARA Group based on EMPR (1991) and B.H. Levelton (1990)

Note on expansion factors: Expansion factors of 2.0 and 2.8 were used for urban planting (instead of 2.5 to 3.2 in A.5 and A.6 above) to take into acount pruning and clearing of non-bolewood biomass (e.g., twigs, etc.) in urban sites. Converting to CO_2 (see A.5 above), the factors are 3.33 to 4.66.

b) Costs

(NO. TREES * COST)	-	PV (ELSAVETOT	* PRICE)	=$
(600,000 trees * $50/tree)	-	10-40 yrs PV (864 TJ/yr	* $4.60/GJ)	=$9 million

Where:

COST	Cost per tree	Assumption
ELSAVETOT	Total electricity saved	ELSAVE * GJ/kwh * TREES
PRICE	Price of electricity	EMPR (1991)
PV	Present value	Electricity savings reaped only after tree has reached a certain height, i.e., after 10 years (assumption)

c) Cost-effectiveness

(i) Total CO_2 fixation & reduction

(17-25 kt CO_2/year * 80 years)

+ (105 kt CO_2/year * 70 years) = 8,710-9,350 kt CO_2

Note: Electricity savings not generated during the first ten years until tree is of adequate size.

(ii) Cost-effectiveness

$9 million -:- 8,710-9,350 kt CO_2 = $6.95-$1.00/tonne CO_2

A.8 Enhance Productivity

a) Abatement potential

(i) Managed Forests

HECTARES	*	GROWTH	*	ADDGR	*	CBIOMASS	*	FACTORS	=	kt CO_2 per year
750,381	*	2.25 m^3/ha/yr	*	4 to 12%	*	.455 t/m^3	*	4.16 to 5.33	=	130 to 490 kt CO2 per year

Where:

HECTARES	Number of hectares in TSA's in age class 1 on good and medium sites	B.C. Ministry of Forests (1984)
GROWTH	Weighted average growth of bolewood and bark for immature interior forest types	Based on B.H. Levelton (1990)
ADDGR	Additional growth attributable to intensive management practices to intensive management practises	Various (see note on derivation of ADDGR)
CBIOMASS	Conversion of annual growth to weight	B.H. Levelton (1990)
FACTORS	Expansion and conversion factors	see A.5 above

Note on indirect emissions: Abatement potential does not account for CO_2 emisions from the production and application of fertilizer of chemicals, or from brushing, weeding and spacing activities.

Derivation of ADDGR

A number of policy documents on global warming cite additional growth benefits from intensive management in the range of 25% to 60%. For a number of reasons, this range appears high for British Columbia. In particular, not all intensive management practices are applicable to all areas in B.C. For example, an "optimistic" estimate for fertilization is 25% of the land base (D. Spittlehouse, B.C. Ministry of Forests, pers. comm.). The following estimates were used in deriving a range of additional growth factors. The estimates are drawn from D. Spittlehouse, B.C. Ministry of Forests (pers. comm.) and Schroeder (1991).

Practice	Land Base[a]	Increments to Growth	
		Spittlehouse	Schroeder
Genetic improvements	18% of planted land	10%	not available
Brushing & weeding[b]	not applicable	0%	5-35%
Fertilization	25%	2-5%	20%
Spacing	30-40%	≤10% (5%)	10%
Total gain by intensive management		4%	12%

Notes:
a. Percent of forested land to which practice is applicable (D. Spittlehouse, pers. comm.)
b. Brushing and weeding are required to maintain base growth rates.

(ii) NSR and Marginal agricultural land

	CO_2 UPTAKE	*	ADDGR	=	kt CO_2 per year
NSR:	2,360-3,020 kt/yr	*	4% to 12%	=	95-360 kt CO_2 per year
Agric: without pastureland:	750-965 kt/yr	*	4% to 12%	=	30-115 kt CO_2 per year
(with pastureland:	1,790-2,290 kt/yr	*	4% to 12%	=	70-275 kt CO_2 per year)

Where:

CO_2UPTAKE	CO_2 uptake from planting NSR lands and marginal agricultural lands	see A.5 and A.6 above

b) Costs

Costs per hectare and applicability to land base are:

Practice	$/ha	Year	PV Costs ($/ha)[a]	Land base	Cost Factor
Survey	13	various	30	100%	30
Genetic improvements	?	/	?	18%	
Brushing & Weeding	289 [b]	5-10	165	20%	33
Fertilization	181	15-20	45	25%	11
Spacing	718	15-20	185	30-40%	(average) 65
Total					$140+/ha[c]

Notes:

a. Because some expenditures are incurred in the future (e.g., 15-20 years after planting), costs are discounted into present value (PV) terms using an 8% discount rate.
b. Chemical treatment.
c. Numbers may not add due to rounding.

Source: R. Brown, B.C. Ministry of Forests (pers. comm.)

Total cost for all plantation types:

(MANAGED + NSR + AGRIC) * COST = $

(750,381 ha + 553,145 ha. + 132,750 ha) * $140/ha = $200 million

with pastureland:

(750,381 ha + 553,145 ha + 315,305 ha) * $140/ha = $225 million

Where:

MANAGED	No. hectares in TSA's in age class 1 on good and medium sites	B.C. Ministry of Forests (1984)
NSR	No. of hectares NSR land replanted	see A.5 above
AGRIC	No. of hectares marginal agricultural land replanted	see A.6 above

c) Cost-effectiveness

(i) Total CO_2 fixation

Annual uptake:

Managed forest	130-490 kt CO_2 per year
NSR	95-360 kt CO_2 per year
Agriculture land	30-115 kt CO_2 per year
(with pastureland	70-275 kt CO_2 per year)
	255-965 kt CO_2 per year
	(295-1,125 kt CO_2 per year)

Uptake over life of measure

255-965/yr * 80 years = 20,400-77,200 kt CO_2

with pastureland: 295-1,125 kt/yr * 80 years = 23,600-90,000 kt CO_2

(ii) Cost-effectiveness

$200 million -:- 20,400 to 77,200 kt CO_2 = $2.60 to $9.80/t CO_2

A.9 Fuel Pellets - Domestic

a) Abatement potential

RES	*	PDPROP	*	[(FFACTOR - WFACTOR)	-	(INPUT * MFACTOR)]	=	kt CO_2/yr
139.34PJ	*	2%	*	[(53.57 kt/PJ - 0 kt/PJ)	-	(.25 * 41.77 kt/PJ)	=	120 kt CO_2/yr

Where:

RES	Residential energy consumption	EMPR (1991)
PDPROP	Proportion of RES diverted to fuel pellets for domestic market	Assumption
FFACTOR	CO_2 emission factor weighted by fuel type for residential sector (non-electric, non-fuel wood)	B.H. Levelton (1990) EMPR (1991)
WFACTOR	CO_2 emission factor for fuel pellets (Note: Equals zero because wood would otherwise have been incinerated)	ARA Consulting Group
INPUT	Energy input required to produce fuel pellets (as percent energy value of pellets)	Assumption
MFACTOR	CO_2 emission factor for fuel used in producing pellets weighted 50% electricity and 50% heavy fuel oil	ARA Consulting Group B.H. Levelton (1990)

b) Costs

Economic viability depends on specific operating market characteristics.

c) Cost-effectiveness

(i) Total emission reductions:

120 kt CO_2/yr * 20 years = 2,400 kt CO_2

(ii) Cost-effectiveness

Not available

A.10 Fuel Pellets -- Export

a) Abatement Potential

WWASTE	*	PXPROP	*	[(FFACTOR - WFACTOR)	-	(INPUT * MFACTOR)]	=	kt CO_2 per year
106.77 PJ	*	5%	*	[(73.11 kt/PJ - Ø)	-	(.25 * 41.77 kt/PJ)]	=	334 kt CO_2/yr

Where:

WWASTE	Wood residue currently incinerated	B.H. Levelton (1991)
PXPROP	Proportion of WWASTE diverted to fuel pellets for export market	Assumption
FFACTOR	CO_2 emission factor for displaced fuel type (Assume light fuel oil)	B.H. Levelton (1991)
WFACTOR INPUT MFACTOR	see A.9	see A.9

b) Costs

Net costs depend on specific operating and market conditions. Expect some viability (Nawitka, 1990).

c) Cost-effectiveness

(i) Total emission reduction

334 kt CO_2/yr * 20 years = 6,680 kt CO_2

(ii) Cost-effectiveness

Costs could be negative in some cases.

A.11 Wood residue Export for Cogeneration

a) Abatement Potential

WWASTE	*	XPROP	*	(FFACTOR	-	WFACTOR)	=	kt CO_2/year
106.77 PJ	*	8%	*	(185 kt/PJ	-	Ø)	=	1,580 kt CO_2/year

Where:

WWASTE	Wood residue currently incinerated	Appendix B
XPROP	Proportion of waste exported for cogeneration (see note below)	Assumption based on Nawitka (1990)

Note: Assumes of 8% of current wood residue is roughly equivalent to 5% of expected California demand for hog fuel for biomass plants of 20 million m^3/year (Nawitka, 1990), estimated as follows:

$$5\% * 20 \text{ million } m^3 * \frac{455 \text{ kg}}{m^3} * \frac{400 \text{ g C}}{\text{kg}} * \frac{\text{TJ}}{22.22 \text{ tC}} = 8{,}191 \text{ TJ} = 8.19 \text{ PJ}$$

All factors from B.H. Levelton (1990)

b) Costs

Economic viability depends on specific supply and market conditions. Expect some viability (Nawitka, 1990).

c) Cost-effectiveness

(i) Total emission reductions

1,580 kt/yr * 10 years = 15,800 kt CO_2

(ii) Cost-effectiveness
Costs could be negative in some cases.

B. Pulp & Paper

B.1 CO_2 Emission Factors

Many of the calculations in the pulp and paper section of the report were based on data provided in the text of that section. However, those calculations did use a variety of CO_2 factors which are derived below.

(i) Base Factors (Thermal, Electricity, All Energy Sources)

Fuel	Share of Energy Consumption			
Thermal (kt/PJ)	**PJ 1989[a]**	**% share**	**CO_2 factor (kt/PJ)**	**Share of CO_2 factor[b]**
NG	23.41	10.3	49.68	5.13
Coal & coke	0.09	~ 0	90.00	0.04
HFO	23.39	10.3	71.54	7.38
LPG	0.33	0.1	70.22	0.10
DFO	0.50	0.2	70.69	0.16
HOG	45.97	20.2	Ø[c]	Ø
LIQ	132.42	58.4	Ø[c]	Ø
OTHER[d]	0.71	0.3	Ø	Ø
	226.82	100.0		12.81 kt/PJ
Electricity (kt/PJ)	**PJ1989[a]**	**% share**	**CO_2 factor (kt/PJ)**	**Share of CO_2 factor[b]**
NG	3.62	6.38	49.68	3.17
HFO	3.12	5.50	71.54	3.93
HOG	3.31	10.77	Ø[c]	Ø
LIQ	6.11	5.83	Ø[c]	Ø
GRID	40.58	71.52	12.32[e]	8.81
	56.74	100.00		15.91 kt/PJ

All Energy Thermal = 80% total energy use; Electricity = 20%

Weighted average CO_2 factor = (.80 * 12.81) + (.20 * 15.91)

= 13.43 kt/PJ

Notes:
- a Sources: B.H. Levelton (1990), EMPR (1991)
- b Source: B.H. Levelton (1990)
- c Assumes waste would be incinerated if not used as energy source; therefore energy use represents non-incremental emissions.
- d "Other" includes mainly self-generated hydro.
- e See Appendix B

B.2 Illustrative Energy Saving Measures From ECO's

Measure	Energy Savings (GJ/ADMT)	Operating Life of Measure	Production Affected (kADMT)	Energy Savings (TJ)	Fuel Price $/GJ	Energy Savings ($000/yr)	Capital Costs ($/GJsaved)	PV Costs ($000s)	CO_2 Factor (t/TJ)	CO_2 Emission Avoided (kt)	$/tonne CO_2
Insulating stock chest newsprint	0.028	10	2,600	72.8	2.08	151	1.0	-783	12.81	9.32	-$85
Reduction of lime kiln heat losses by low emissivity paint - kraft	0.116	3	5,000	580.0	2.08	1206	0.61	-2544	12.81	7.43	-$340
Recovery and reuse of paper machine white water - newsprint	0.05	15	2,600	130.0	2.08	270	.01	-1840	12.81	1.67	-$1100

NOTES:
a Energy Conservation Opportunity documentation
b Weighted average price for thermal energy (assumes self-generated fuels are free)
c Thermal energy factor (see B.1)

B.3 Energy Efficient Motors

a) Abatement potential

SAVE	* MDEMAND	* TJ/Gwh	* FACTOR	=kt CO_2 per year
1.50%	* 15,136 Gwh/yr	* 3.6TJ/Gwh	* 12.32 t/TJ	=10.07 kt CO_2/yr

Where:

SAVE	Percent electricity saving from energy efficient motors	Tom Cave, BCH (pers. comm.)
MDEMAND	Electrical demand for motors (approx.) NOTE: BCH demand only.	J. Gibbon, BCH (per. comm.)
FACTOR	CO_2 emission factor for B.C. Hydro power	Appendix B

b) Costs

-PV (ELSAVE	* PRICE)	+ KCOST	= $
-PV (817 TJ	* $6.647/GJ)	+ $17 million	= - $2.6 million

Where:

ELSAVE	Electricity savings (1.5% * 15,136 * 3.6)	B.2 Part a) above
PRICE	Price of BCH electricity, industrial	EMPR (1991)
KCOST	Capital cost	see note below
PV	Present value over 5 years at 12% discount rate	ARA Consulting Group

Note: Capital cost approximated on the basis of a 3.5 year payback (H.A. Simons, 1985) as follows:

Payback of 4 years implies:

PV of annual cost savings over 4 years = capital cost
PV ($5.40 million @ 12%) over 4 years = $17 million
where $5.40 million is the annual electricity cost savings (817 TJ * $6.647/TJ) and savings are discounted at 12%

c) Cost-effectiveness

(i) Total emission reductions

10.07 kt/yr * 5 years = 50.35 kt CO_2 per year

(ii) Cost-effectiveness

- $2.6 million -:- 50.35 kt = - $52/tonne

B.4 Variable Speed Drives

A) Abatement potential

(DEMANDA	*	PRODA	*	(1 - RATE)	*	TIMEA	*	SAVEA)
(3.84 kW/t	*	7,236 kt	*	(1 - .90)	*	24 hrs/d	*	31.5%)
+ (DEMANDB	*	PRODB	*	(1 - RATE)	*	TIMEB	*	SAVEB)
(7.40 kW/t	*	2,878 kt	*	(1 - .90)	*	23.5 hrs/d	*	30.9%)

*	TJ/Gwh	*	FACTOR	=kt CO_2 per year
*	3.6 TJ/Gwh	*	12.32 t/TJ	= 14.5 kt/yr

Where:

DEMAND A,B	Potential adjustable speed applications	H.A. Simons (1985)
PROD A,B	Levels of production (1988) of pulp and paper	Statistics Canada (36 - 250)
RATE	Implementation rate	H.A. Simons (1985)
TIME A,B	Operating time for	Perrson, HASmins pers. comm.
SAVE A,B	Energy saving from variable speed drives	H.A. Simons (1985)
FACTOR	CO_2 emission factor for BCH power	Appendix B

b) Costs

-PV (ESAVE	*	TJ/Gwh	*	PRICE)	+	KCOST	=	$
-PV ((189 + 139 Gwh)	*	3.6 TJ/Gwh	*	$6.647/GJ)	+	$15.6m	=	- $12.7 million

Where:

ESAVE	Electricity savings	B.3 Part a)
PRICE	Price of electricity from BC Hydro grid (industrial)	EMPR (1991)
KCOST	Incremental capital cost	see note below

Note: Incremental capital cost estimated as follows: Variable speed drives cost about $100 - 200/hsp; assume $200/hsp or $270/kw (Perrson, H.A. Simons, pers. comm.). Non-variable speed drives cost approx. one third of variable speed drives, or $90/kw. The incremental capital cost, therefore, is $180/kw.

$$\text{Incremental Capital Cost} = \left(\frac{189\ \text{Gwh}}{31.5\%} - 189\ \text{Gwh}\right) + \left(\frac{139\ \text{Gwh}}{30.9\%} - 139\ \text{Gwh}\right) * \frac{12\ \text{MW}}{\text{Gwh/yr}} * \$180/\text{kw} = \$15.6\ \text{million}$$

c) **Cost-effectiveness**

(i) Total emission reduction

14.5 kt/yr * 5 years = 72.5 kt CO_2 per year

(ii) Cost-effectiveness

- $12.7 million -:- 72.5 kt = - $175/tonne

B.5 Energy Efficient Lighting

a) Abatement potential

ELSAVE	*	PERCENT	*	ELDEMAND	*	FACTOR	=	kt CO_2/yr
12 % to 50%	*	4%	*	56.74 PJ	*	15.91 t/TJ	=	4 to 18 kt/yr

Where:

ELSAVE	Percent electricity savings for retrofits or new lighting investments.	OTA (1991)
PERCENT	Lighting as percent total electricity use in pulp and paper sector.	H.A. Simons
ELDEMAND	Electricity demand in pulp and paper.	
FACTOR	CO_2 emission factor for pulp and paper electricity (weighted average self-generated and grid).	see B.1

b) Costs

- PV (ELSAVE 1-10 yrs	*	PRICE)	+	(ELSAVE	*	KCOST)	=	$
- PV(.27 to 1.13 PJ 1-10 yrs	*	$6.64/GJ)	+	(.27 to 1.13 PJ	*	$6.60/GJ)	=	- $8.3 to 34.9 million

Where:

PRICE	Price of electricity (industrial customer, BC Hydro).	EMPR (1991)
KCOST	Capital cost	The DPA Group (1989)

c) **Cost-Effectiveness**

(i) Total emission reductions

4 to 18 kt/yr * 10 years = 40 to 180 kt CO_2 per year

(ii) Cost-effectiveness

- $8.3 to $34.9 million -:- 40 to 180 kt ~ - $195 - 205/tonne

B.6 Heat Pinch Technology

a) Abatement potential

TESAVE	* TEDEMAND	* TEFACTOR	=kt CO_2 per year
36%	* 226.82 PJ	* 12.81 kt/PJ	= 1,046 kt/year

Where:

TESAVE	Percent thermal energy savings from heat pinch technology.	Herzog & Tester (no date)
TEDEMAND	Thermal energy demand in pulp and paper.	EMPR (1991)
TEFACTOR	CO_2 emission factor for thermal energy in pulp and paper.	see B.1

b) Costs

- PV (TESAVE 1-10 years	* TEDEMAND	* PRICE)	+ KCOST	= $		
- PV (36% 1-10 years	* 226.82 PJ	* $2.08/GJ)	+ $287 million	=	- $673 million	

Where:

TEPRICE	Weighted average price for thermal energy (assumes self-generated fuels are free).	ARA Consulting Group EMPR (1991)
KCOST	Capital Cost	see note below

Note: Capital cost for heat pinch technology is based on a payback of 6 m to 2 years; assume 2 years (Herzog & Tester, no date). Implementing the technology in a new plant could generate savings in the order of 25%.

KCOST	=	PV (36% 2 years	* 226.82 PJ	* $2.08/GJ)	= $287 million

C) Cost-effectiveness

(i) Total emission reduction

1,046 kt/yr * 10 yrs = 10,460 kt CO_2 per year

(ii) Cost-effectiveness

-$673 million -:- 10,460 kt = -$64/tonne

B.7 State-of-Art Digesters

a) Abatement potential

SAVE	* OUTPUT	* FACTOR	=kt CO_2 per year
4GJ/kADMT	* 5,000 kADMT	* 12.81 t/TJ	= 255 kt/year

Where:

SAVE	Energy savings from state-of-art digesters.	Herzog & Tester (no date)
OUTPUT	Kraft production in B.C.	H.A. Simons
FACTOR	CO_2 emission factor for thermal energy.	see B.1

b) Costs

No data available, but capital costs tend to be high and represent the main obstacle to adoption (Herzog & Tester, no date; Grant, 1983).

c) Cost-effectiveness

(i) Total emission reduction

255 kt/yr * 10 years = 2,550 kt CO_2 per year

(ii) Cost-effectiveness

Not available.

B.8 Impulse Drying

a) Abatement potential

SAVE	* OUTPUT	* FACTOR	=kt CO_2 per year
2.5 GJ/ADMT	* 5,000 k ADMT	* 13.43 t/TJ	= 168 kt/year

Where:

SAVE	Energy savings.	Herzog & Tester (1991)
OUTPUT	Production by Kraft mills in B.C.	H.A. Simons
FACTOR	CO_2 emission factor for pulp and paper (average of electricity and thermal).	see B.1

b) Costs

No data available for capital costs, although costs should be lower in new installations as the impulse dryer should replace one or two presses and much of the dryer section (Sprague, 1987).

c) Cost-effectiveness

(i) Total emission reductions

168 kt/yr * 10 years = 1,680 kt CO_2 per year

(ii) Cost-effectiveness

Not available.

B.9 State-of-Art Evaporation

Two technologies are included: MEE (multiple effect evaporation) and VRE (vapour recompression evaporation).

a) Abatement potential

SAVE	*	SHARE	*	ENERGY	*	OUTPUT	*	FACTOR	=	kt CO_2 per year
40%	*	13%	*	18.7 GJ/ADMT	*	5,000 kADMT	*	12.81 t/TJ	=	62 kt/year

Where:

SAVE	Percent energy savings in evaporation.	Elaahi & Lowitt in Herzog & Tester (1991)
SHARE	Share of total energy used in evaporation.	Hersh in Herzog & Tester (1991)
ENERGY	Unit energy demand.	
OUTPUT	Kraft production.	H.A. Simons
FACTOR	CO_2 factor for thermal energy.	see B.1

b) Costs

No data available.

c) Cost-effectiveness

(i) Total emission reduction

62 kt/yr + 10 years = 620 kt CO_2 per year

(ii) Cost-effectiveness

Not available

B.10 Substitute from Kraft to Recycle Mills

a) Abatement potential

FACTORDIFF	*	PROD	=	kt CO_2 per year
(995 - 22 kg/ADMT)	*	2,000 kADMT	=	1,946 kt/year

Where:

FACTORDIFF	Difference in CO_2 emission factor between kraft and recycle production.	See Section 4.3
PROD	Kraft production affected.	Assumption

b) Costs

Depends on variety of factors. Comprehensive analysis outside scope of study. However, likely cost-effective under some conditions.

c) Cost-effectiveness

(i) Total emission reduction

1,946 kt/yr * 20 years = 38,920 kt CO_2 per year

(ii) Cost-effectiveness

Not available

B.11 Substitution to 100% Self-Generated Fuels

a) Abatement potential

PFUEL	*	DIFFFACTOR	=	kt CO_2 per year
95.05 PJ	*	40.04 kt/PJ	=	3,806 kt/year

Where:

PFUEL	Purchased fuel and electric in pulp and paper sector.	EMPR (1991)
DIFFACTOR	CO_2 emission factor for purchased fuels.	see B.1

b) Costs

Comprehensive data not available. However, Poyry (1986) indicates that incremental capital costs for new mills may be negligible.

C) Cost-effectiveness

(i) Total emission reduction

3,806 kt/yr * 20 years = 76,116 kt CO_2 per year

(ii) Cost-effectiveness

Not available

B.12 Substitution to Natural Gas

a) Abatement potential

(HFO	* HFOFACTOR)	+	(DFO	* DFOFACTOR)	-	
(23.39 PJ	* 71.54 kt/PJ)	+	(.50 PJ	* 70.69 kt/PJ)	-	
(NGAS	* EFFICIENCY	*NGAS FACTOR)	=kt CO_2 per year			
(23.89 PJ	* 85%/80%	* 49.68 kt/PJ)	= 447 kt/yr			

Where:

HFO, DFO	Consumption of HFO and DFO in pulp and paper sector.	EMPR (1991)
HFO/DFOFACTOR	CO_2 emission factors for HFO and DFO.	BHLevelton (1990)
NGAS	Substitute volume of natural gas.	HFO + DFO
EFFICIENCY	Relative efficiency factor (natural gas vs. oil).	Soulsby (1991)
NGAS FACTOR	CO_2 emission factor for natural gas.	BHLevelton (1990)

b) Costs

PV [-(HFO * HFOPRICE) - (DFO * DFOPRICE) + (NGAS * EFFICIENCY *NGASPRICE)]
1-20 yrs

PV [-(23.39 PJ * $3.39/GJ) - (.50 PJ * $3.39/GJ) +(23.89 PJ * 85/80 * $2.08/GJ)]
1-20 yrs

=-$355 million

Where:

HFO/DFO/NGAS PRICE	Price for HFO, DFO AND natural gas.	EMPR (1991)

NOTE: Fuel savings only

c) **Cost-effectiveness**

(i) Total emission reduction

447 kt/year * 20 years = 8,940 kt CO_2 per year

(ii) Cost-effectiveness

-$355 million -:- 8,940 kt = -$40/tonne

C. Road Transportation

Carbon dioxide abatement potential and cost-effectiveness for the majority of measure were calculated in the following work sheets. The list of measures, percent energy savings, incremental and operating costs are largely taken from Alberta Energy (1991). However, some of the values used in those worksheets were based on other assumptions as presented below.

C.1 Emission Factors by Fuel Type

The folowing emission factors were used:

FUEL	t CO_2 per TJ[a]
Gasoline	67.98
Methanol (from natural gas)	66.62
Diesel	60.50
Propane	57.78
CNG	57.10
Ethanol (from wood)	23.79
Electricity	12.32

Notes:

a. Based on emision factors for gasoline (B.H. Levelton 1990) and relative factors for other fuels (L. Vancea, EMR, pers comm.). Life-cycle basis, including consideration of relative fuel efficiencies.

b. Assumes share of hydropower remains at current levels in British Columbia.

These factors differ from those used in the B.H. Levelton CO_2 inventory, but reflect transportation-specific factors for each fuel type.

C.2 Route and Traffic Planning

	SAVINGS	*	URBAN	=	Provincial energy savings (%)
Private	10%	*	60%	=	6%
Commercial	15%	*	45%	=	7%

Where:

SAVING	Energy savings in urban areas.	See Section 5.2
URBAN	Urban fuel use as percent provincial total.	ARA Consulting Group based on GVRD share of provincial population (45%) and The DPA Group Inc. (1989)

C.3 Staggered Work Hours/Compressed Work Week (including telecommuting)

SAVING	*	URBAN	*	COMMUTE	=	Provincial energy savings (%)
10%	*	60%	*	30%	=	1.8%

Where:

SAVING	Energy saving for urban commuting.	See Section 5.2
URBAN	Urban fuel use as percent provincial total.	See C.1
COMMUTE	Fuel use during work travel periods.	Assumption

Note: Applicable to private transportation only.

C.4 Intermodal Shift (Trucks to Rail)

The Railway Association of Canada project growth in rail traffic *from intermodal shift from trucks* at about 10% over 20 years. The savings in fuel is about 75%. (Alberta Energy, 1991). For the purposes of this study, we have assumed a 20% shift with net fuel savings of 75% for overall sector savings of 15%.

C.5 Increased Transit Use (Public Transportation)

A 50% increase in transit's share of urban passenger-trips (see Section 5.2) implies a 6% decrease in private vehicle passenger trips:

	share before measures	% change	share after measures
transit	10.1%	+50%	15.2%
private	89.9%	-5.7%	84.8%

Decrease in passenger-trips by cars is then modified to take into account average passenger load per vehicle, differential fuel consumption per passenger-trip and urban share of private vehicle fuel use:

-5.7%/AVR	*	FUEL	*	URBAN	=	Provincial energy savings (%)
-5.7%/1.1	*	90%	*	60%	=	2.8%

Where:

AVR	Average vehicle ridership (number of passengers per vehicle) based on 24-hour period.	TransVision Consultants (1990) Table 22
FUEL	Fuel consumption of buses/transit per passenger-trip is 90% that of private vehicles.	TransVision Consultants (1990) Exhibit 9

Emission factors "after the measure" are weighted averages of electricity and the fuel type "before the measure". Fuel prices are also weighted averages. Number of units are given in increased annual ridership.

Capital costs are taken from VHB Research & Consulting (1991). Incremental operating costs (e.g., avoided parking charges, transit fare) are excluded, although energy, (the largest cost component) are calculated.

C.6 Trip Reduction Measures

Increase in AVR from 1.3 to 1.5 people corresponds to a decrease in urban traffic of about 15%. Assuming the reduction in number of trips results in an equivalent reduction in fuel consumption, provincial energy savings are calculated as:

DAVR	*	URBAN	=	Provincial energy savings (%)
15%	*	60%	=	9%

Where:

DAVR	Decrease in peak period AVR due to trip reduction measures.	ARA Consulting Group based on SCAQMP and City of Vancouver (1990)
URBAN	Urban fuel use as percent of provincial total.	see C.1

C.7 Interfuel Substitution

Assumes 50% of gasoline fleet converts to alternative fuel. CO_2 emission factors and fuel prices after measure are weighted averages of gasoline and alternative fuel.

C.8 Vehicle Efficiency

Cost per vehicle from VHB Research & Consulting (1991).

TRANS 31-Jan-92 12%

Sector	Number of Units	Name of Measure	Fuel Type Before Measure	Fuel Type After Measure	Fuel Use Before Measure (PJ)	Fuel Use After Measure (PJ)	Provincial Energy Savings (%)	Operating Life of Measure	Incremental Operating Cost Unit (000's/yr)	Incremental Operating Cost Sector (000's)	Capital Costs Unit (000's)	Capital Costs Sector (000's)
Transportation												
Private												
	16813	driver training	DFO	DFO	11.54	11.19	3.0%	50	0	0	0.05	841
	1435342	driver training	MOG	MOG	83.27	80.77	3.0%	50	0	0	0.05	71767
	11000	driver training	NGS	NGS	0.64	0.62	3.0%	50	0	0	0.05	550
	16000	driver training	propane	propane	0.92	0.89	3.0%	50	0	0	0.05	800
	717671	fuel conversion	MOG	NGS	83.27	83.27	0.0%	10	-0.08	-57413.68	1.8	1291808
	717671	fuel conversion	MOG	propane	83.27	83.27	0.0%	10	-0.08	-57413.68	1.8	1291808
	717671	fuel conversion	MOG	DFO	83.27	83.27	0.0%	10	0	0	1.8	1291808
	717671	fuel conversion	MOG	ELEC	83.27	83.27	0.0%	10	0		0	0
	16813	route planning	DFO	DFO	11.54	10.85	6.0%	20	0	0		0
	1435342	route planning	MOG	MOG	83.27	78.27	6.0%	20	0	0		0
	11000	route planning	NGS	NGS	0.64	0.60	6.0%	20	0	0		0
	16000	route planning	propane	propane	0.92	0.87	6.0%	20	0	0		0
	16813	Staggered Work/Compressed Week	DFO	DFO	11.54	11.33	1.8%	20	0	0		0
	1435342	Staggered Work/Compressed Week	MOG	MOG	83.27	81.77	1.8%	20	0	0		0
	11000	Staggered Work/Compressed Week	NGS	NGS	0.64	0.63	1.8%	20	0	0		0
	16000	Staggered Work/Compressed Week	propane	propane	0.92	0.91	1.8%	20	0	0		0
	1290	Public Transport	NGS	mix	0.64	0.62	2.8%	25	0	0	1.3	1677
	1880	Public Transport	Propane	mix	0.92	0.90	2.8%	25	0	0	1.3	2444
	1980	Public Transport	DFO	mix	11.54	11.22	2.8%	25	0	0	1.3	2574
	168782	Public Transport	MOG	mix	83.27	80.94	2.8%	25	0	0	1.3	219417
	11000	vehicle maintenance	NGS	NGS	0.64	0.61	5.0%	2	0	0	0.05	550
	16000	vehicle maintenance	propane	propane	0.92	0.88	5.0%	2	0	0	0.05	800
	16813	vehicle maintenance	DFO	DFO	11.54	10.96	5.0%	2	0	0	0.05	841
	1435342	vehicle maintenance	MOG	MOG	83.27	79.11	5.0%	2	0	0	0.05	71767
	16813	vehicle retrofits	DFO	DFO	11.54	11.42	1.0%	10	0	0	0.25	4203
	1435342	vehicle retrofits	MOG	MOG	83.27	82.44	1.0%	10	0	0	0.25	358836
	16000	vehicle retrofits	propane	propane	0.92	0.91	1.0%	10	0	0	0.25	4000
	11000	vehicle retrofits	NGS	NGS	0.64	0.63	1.0%	10	0	0	0.25	2750
	717671	vehicle efficiency	MOG	MOG	83.27	69.11	17.0%	10	0	0	1.24	889912
	8406	vehicle efficiency	DFO	DFO	11.54	9.58	17.0%	10	0	0	1.24	10423
	16813	trip reduction	DFO	DFO	11.54	10.50	9.0%	20	0	0		0
	1435342	trip reduction	MOG	MOG	83.27	75.78	9.0%	20	0	0		0
	11000	trip reduction	NGS	NGS	0.64	0.58	9.0%	20	0	0		0
	16000	trip reduction	propane	propane	0.92	0.84	9.0%	20	0	0		0
Commercial												
	491798	driver training	MOG	MOG	46.03	43.27	6.0%	40	0	0	0.1	49180
	45000	driver training	propane	propane	4.20	3.95	6.0%	40	0	0	0.1	4500
	47457	driver training	DFO	DFO	32.85	30.88	6.0%	40	0	0	0.1	4746
	3000	driver training	NGS	NGS	0.29	0.27	6.0%	40	0	0	0.1	300
	245900	fuel conversion	MOG	NGS	46.03	46.03	0.0%	10	-0.08	-19672	1.8	442620
	245900	fuel conversion	MOG	propane	46.03	46.03	0.0%	10	-0.08	-19672	1.8	442620
	245900	fuel conversion	MOG	DFO	46.03	46.03	0.0%	10	0	0	1.8	442620
	47457	intermodal shift	DFO	mix	32.85	27.92	15.0%	25	?	0	?	0
	491798	intermodal shift	MOG	mix	46.03	39.13	15.0%	25	?	0	?	0

47457	route planning	DFO	DFO	32.85	30.55	7.0%	20	0	0		0
45000	route planning	propane	propane	4.20	3.91	7.0%	20	0	0		0
3000	route planning	NGS	NGS	0.29	0.27	7.0%	20	0	0		0
491798	route planning	MOG	MOG	46.03	42.81	7.0%	20	0	0		0
45000	vehicle maintenance	propane	propane	4.20	4.03	4.0%	1	0.05	2250		0
47457	vehicle maintenance	DFO	DFO	32.85	31.54	4.0%	1	0.05	2372.85		0
3000	vehicle maintenance	NGS	NGS	0.29	0.28	4.0%	1	0.05	150		0
491798	vehicle maintenance	MOG	MOG	46.03	44.19	4.0%	1	0.05	24589.9		0
491798	vehicle retrofits	MOG	MOG	46.03	44.65	3.0%	10	0	0	0.3	147539
45000	vehicle retrofits	propane	propane	4.20	4.08	3.0%	10	0	0	0.3	13500
3000	vehicle retrofits	NGS	NGS	0.29	0.28	3.0%	10	0	0	0.3	900
47457	vehicle retrofits	DFO	DFO	32.85	31.86	3.0%	10	0	0	0.3	14237
245900	vehicle efficiency	MOG	MOG	46.03	38.21	17.0%	10	0	0	1.24	304916
23728	vehicle efficiency	DFO	DFO	32.85	27.27	17.0%	10	0	0	1.24	29423

Sector	Name of Measure	CO2 Emission Factor Before Measure (kt/PJ)	CO2 Emissions Before Measure (kt/yr)	CO2 Emission Factor After Measure (kt/PJ)	CO2 Emission After Measure (kt/yr)	Annual Reduction in Emissions (kt/yr)	Lifetime Reduction in Emissions (kt)
Transportation							
Private							
	driver training	60.50	698.170	60.50	677.225	20.95	1047.255
	driver training	67.98	5660.698	67.98	5490.877	169.82	8491.047
	driver training	57.10	36.516	57.10	35.420	1.10	54.774
	driver training	57.78	53.302	57.78	51.703	1.60	79.953
	fuel conversion	67.98	5660.698	62.54	5207.709	452.99	4529.891
	fuel conversion	67.98	5660.698	62.88	5236.021	424.68	4246.772
	fuel conversion	67.98	5660.698	64.24	5349.268	311.43	3114.300
	fuel conversion	67.98	5660.695	62.41	5196.881	463.81	4638.139
	route planning	60.50	698.170	60.50	656.280	41.89	837.804
	route planning	67.98	5660.698	67.98	5321.056	339.64	6792.838
	route planning	57.10	36.516	57.10	34.325	2.19	43.819
	route planning	57.78	53.302	57.78	50.104	3.20	63.962
	Staggered Work/Compressed Wee	60.50	698.170	60.50	685.603	12.57	251.341
	Staggered Work/Compressed Wee	67.98	5660.698	67.98	5558.805	101.89	2037.851
	Staggered Work/Compressed Wee	57.10	36.516	57.10	35.858	0.66	13.146
	Staggered Work/Compressed Wee	57.78	53.302	57.78	52.343	0.96	19.189
	Public Transport	57.10	36.516	54.41	33.821	2.69	67.364
	Public Transport	57.78	53.302	55.05	49.362	3.94	98.509
	Public Transport	60.50	698.170	57.61	646.204	51.97	1299.139
	Public Transport	67.98	5660.698	64.64	5231.864	428.83	10720.852
	vehicle maintenance	57.10	36.516	57.10	34.690	1.83	3.652
	vehicle maintenance	57.78	53.302	57.78	50.637	2.67	5.330
	vehicle maintenance	60.50	698.170	60.50	663.262	34.91	69.817
	vehicle maintenance	67.98	5660.698	67.98	5377.663	283.03	566.070
	vehicle retrofits	60.50	698.170	60.50	691.188	6.98	69.817
	vehicle retrofits	67.98	5660.698	67.98	5604.091	56.61	566.070
	vehicle retrofits	57.78	53.302	57.78	52.769	0.53	5.330
	vehicle retrofits	57.10	36.516	57.10	36.151	0.37	3.652
	vehicle efficiency	67.98	5660.698	67.98	4698.379	962.32	9623.186
	vehicle efficiency	60.50	698.170	60.50	579.481	118.69	1186.889
	trip reduction	60.50	698.170	60.50	635.335	62.84	1256.706
	trip reduction	67.98	5660.698	67.98	5151.235	509.46	10189.256
	trip reduction	57.10	36.516	57.10	33.229	3.29	65.728
	trip reduction	57.78	53.302	57.78	48.505	4.80	95.944
Commercial							
	driver training	67.98	3129.222	67.98	2941.469	187.75	7510.133
	driver training	57.78	242.820	57.78	228.251	14.57	582.769
	driver training	60.50	1987.425	60.50	1868.180	119.25	4769.820
	driver training	57.10	16.406	57.10	15.421	0.98	39.374
	fuel conversion	67.98	3129.222	57.10	2628.399	500.82	5008.229
	fuel conversion	67.98	3129.222	57.78	2659.701	469.52	4695.214
	fuel conversion	67.98	3129.222	60.50	2784.906	344.32	3443.157
	intermodal shift	60.50	1987.425	60.50	1689.311	298.11	7452.844
	intermodal shift	67.98	3129.119	67.54	2642.536	486.58	12164.578

route planning	60.50	1987.425	60.50	1848.305	139.12	2782.395
route planning	57.78	242.820	57.78	225.823	17.00	339.949
route planning	57.10	16.406	57.10	15.257	1.15	22.968
route planning	67.98	3129.222	67.98	2910.177	219.05	4380.911
vehicle maintenance	57.78	242.820	57.78	233.108	9.71	9.713
vehicle maintenance	60.50	1987.425	60.50	1907.928	79.50	79.497
vehicle maintenance	57.10	16.406	57.10	15.749	0.66	0.656
vehicle maintenance	67.98	3129.222	67.98	3004.053	125.17	125.169
vehicle retrofits	67.98	3129.222	67.98	3035.346	93.88	938.767
vehicle retrofits	57.78	242.820	57.78	235.536	7.28	72.846
vehicle retrofits	57.10	16.406	57.10	15.913	0.49	4.922
vehicle retrofits	60.50	1987.425	60.50	1927.802	59.62	596.228
vehicle efficiency	67.98	3129.222	67.98	2597.254	531.97	5319.678
vehicle efficiency	60.50	1987.425	60.50	1649.563	337.86	3378.623

Sector	Name of Measure	Fuel Type After Measure	Fuel Price Before Measure ($000's/PJ	Fuel Cost Before Measure ($000's/PJ)	Incremental Operating Cost Sector (000's/yr)	Fuel Price After Measure ($000's/PJ)	Fuel Costs After Measure ($000's/PJ)	Net Operating Costs (OOO'S/ yr	Present Value Net Operating Costs ($000's)	Capital Costs Sector ($000's)	Total Lifetime Cost of Measure ($000's)	Payback of Measure (yrs)	Cost-Effectiveness ($/t)
Transportation													
Private													
	driver training	DFO	12420	143327	0	12420	139027	-4300	-35708	841	-34867	-0.20	-33.29
	driver training	MOG	15216	1267037	0	15216	1229026	-38011	-315663	71767	-243896	-1.89	-28.72
	driver training	NGS	7620	4873	0	7620	4727	-146	-1214	550	-664	-3.76	-12.12
	driver training	propane	4510	4160	0	4510	4036	-125	-1037	800	-237	-6.41	-2.96
	fuel conversion	NGS	15216	1267037	-57414	11448	953276	-371175	-2097223	1291808	-805415	-3.48	-177.80
	fuel conversion	propane	15216	1267037	-57414	9863	821292	-503158	-2842956	1291808	-1551149	-2.57	-365.25
	fuel conversion	DFO	15216	1267037	0	13818	1150626	-116412	-657751	1291808	634057	-11.10	203.60
	fuel conversion	ELEC	15216	1267036	0	15131	1259958	-7078	-39992		-39992	0.00	-8.62
	route planning	DFO	12420	143327	0	12420	134727	-8600	-64234	0	-64234	0.00	-76.67
	route planning	MOG	15216	1267037	0	15216	1191015	-76022	-567844	0	-567844	0.00	-83.59
	route planning	NGS	7620	4873	0	7620	4581	-292	-2184	0	-2184	0.00	-49.84
	route planning	propane	4510	4160	0	4510	3911	-250	-1865	0	-1865	0.00	-29.15
	Staggered Work/Compresse	DFO	12420	143327	0	12420	140747	-2580	-19270	0	-19270	0.00	-76.67
	Staggered Work/Compresse	MOG	15216	1267037	0	15216	1244230	-22807	-170353	0	-170353	0.00	-83.59
	Staggered Work/Compresse	NGS	7620	4873	0	7620	4785	-88	-656	0	-656	0.00	-49.91
	Staggered Work/Compresse	propane	4510	4160	0	4510	4086	-75	-559	0	-559	0.00	-29.15
	Public Transport	mix	7620	4873	0	8023	4967	114	894	1677	2571	14.72	38.16
	Public Transport	mix	4510	4160	0	5100	4573	413	3236	2444	5680	5.92	57.66
	Public Transport	mix	12420	143327	0	12535	140604	-2723	-21359	2574	-18785	-0.95	-14.46
	Public Transport	mix	15216	1267037	0	15163	1227270	-39767	-311896	219417	-92480	-5.52	-8.63
	vehicle maintenance	NGS	7620	4873	0	7620	4630	-244	-412	550	138	-2.26	37.85
	vehicle maintenance	propane	4510	4160	0	4510	3952	-208	-352	800	448	-3.85	84.13
	vehicle maintenance	DFO	12420	143327	0	12420	136160	-7166	-12111	841	-11271	-0.12	-161.43
	vehicle maintenance	MOG	15216	1267037	0	15216	1203685	-63352	-107068	71767	-35301	-1.13	-62.36
	vehicle retrofits	DFO	12420	143327	0	12420	141894	-1433	-8098	4203	-3895	-2.93	-55.79
	vehicle retrofits	MOG	15216	1267037	0	15216	1254367	-12670	-71590	358836	287245	-28.32	507.44
	vehicle retrofits	propane	4510	4160	0	4510	4119	-42	-235	4000	3765	-96.14	706.34
	vehicle retrofits	NGS	7620	4873	0	7620	4824	-49	-275	2750	2475	-56.58	677.89
	vehicle efficiency	MOG	15216	1267037	0	15216	1051641	-215396	-1217037	889912	-327125	-4.13	-33.99
	vehicle efficiency	DFO	12420	143327	0	12420	118961	-24366	-137671	10423	-127247	-0.43	-107.21
	trip reduction	DFO	12420	143327	0	12420	130427	-12899	-96351	0	-96351	0.00	-76.67
	trip reduction	MOG	15216	1267037	0	15216	1153004	-114033	-851766	0	-851766	0.00	-83.59
	trip reduction	NGS	7620	4873	0	7620	4434	-439	-3276	0	-3276	0.00	-49.84
	trip reduction	propane	4510	4160	0	4510	3786	-374	-2797	0	-2797	0.00	-29.15
Commercial													
	driver training	MOG	15216	700415	0	15216	658391	-42025	-346444	49180	-297264	-1.17	-39.58
	driver training	propane	4510	18953	0	4510	17816	-1137	-9375	4500	-4875	-3.96	-8.36
	driver training	DFO	12420	407997	0	12420	383517	-24480	-201806	4746	-197060	-0.19	-41.31
	driver training	NGS	7620	2189	0	7620	2058	-131	-1083	300	-783	-2.28	-19.86
	fuel conversion	NGS	15216	700415	-19672	7620	350769	-369318	-2086730	442620	-1644110	-1.20	-328.28
	fuel conversion	propane	15216	700415	-19672	4510	207602	-512485	-2895657	442620	-2453037	-0.86	-522.45
	fuel conversion	DFO	15216	700415	0	12420	571711	-128704	-727207	442620	-284587	-3.44	-82.65
	intermodal shift	mix	12420	407997	0	12420	346797	-61200	-479997	0	-479997	0.00	-64.40
	intermodal shift	mix	15216	700392	0	15216	595334	-105059	-823991	0	-823991	0.00	-87.74

route planning	DFO	12420	407997	0	12420	379437	-28560	-213326	0	-213326	0.00	-76.67
route planning	propane	4510	18953	0	4510	17627	-1327	-9910	0	-9910	0.00	-29.15
route planning	NGS	7620	2189	0	7620	2036	-153	-1145	0	-1145	0.00	-49.84
route planning	MOG	15216	700415	0	15216	651386	-49029	-366220	0	-366220	0.00	-83.59
vehicle maintenance	propane	4510	18953	2250	4510	18195	1492	1332	0	1332	0.00	137.14
vehicle maintenance	DFO	12420	407997	2373	12420	391677	-13947	-12453	0	-12453	0.00	-156.64
vehicle maintenance	NGS	7620	2189	150	7620	2102	62	56	0	56	0.00	84.93
vehicle maintenance	MOG	15216	700415	24590	15216	672399	-3427	-3060	0	-3060	0.00	-24.44
vehicle retrofits	MOG	15216	700415	0	15216	679403	-21012	-118725	147539	28814	-7.02	30.69
vehicle retrofits	propane	4510	18953	0	4510	18385	-569	-3213	13500	10287	-23.74	141.22
vehicle retrofits	NGS	7620	2189	0	7620	2124	-66	-371	900	529	-13.70	107.46
vehicle retrofits	DFO	12420	407997	0	12420	395757	-12240	-69158	14237	-54921	-1.16	-92.11
vehicle efficiency	MOG	15216	700415	0	15216	581345	-119071	-672776	304916	-367860	-418530	-69.15
vehicle efficiency	DFO	12420	407997	0	12420	338638	-69359	-391897	29423	-362474	-412403	-107.28

D. Residential

The working tables for residential management measures (see pages following) are based on the following data sources:

Item/Element	Source
1. List of measures Percent energy savings Operating life of measure Incremental operating costs Capital costs	ARA Consulting Group based on The DPA Group Inc. (1989)
2. Fuel use before measure Fuel price before/after measure	EMPR (1991)
3. CO_2 emission factors	B.H. Levelton (1990)
4. Percent fuel use affected	ARA Consulting Group based on national data

02-Feb-92 RESID1 12%

Sector	Name of Measure	Fuel Type Before Measure	Fuel Typ After Measure	Fuel Use Before Measure	Fuel Use After Measure	Percent Fuel Use affected	Percent Energy Savings	Operatin Life of Measure	Number of Units	Incremental Operating Cos per year (000's/unit)	Incremental Operating C per year Sector (000's)	Capital Costs (000's/unit)	Capital Costs Sector (000's)
RESIDENTIAL HOUSING													
	user education/practices	NGS	NGS	78.34	70.51	100	10	50	464041	0	0	0	0
	user education/practices	electric	electric	44.81	40.33	100	10	50	149638	0	0	0	0
	user education/practices	LFO	LFO	11.55	10.40	100	10	50	173581	0	0	0	0
	air conditioning (improved efficiency)	electric	electric	44.81	44.81	0.07	10	20	149638	0.03	4489.14	0.1	14963.8
	appliances & fixtures (improved efficiency)	electric	electric	44.81	44.21	4.5	30	20	149638	0	0	0.1	14963.8
Space Heating	energy efficient new housing	LFO	LFO	11.55	9.76	44.3	35	50	173581	0	0	2.5	433952.5
	energy efficient new housing	electric	electric	44.81	42.05	17.6	35	50	149638	0	0	2	299276
	energy efficient new housing	NGS	NGS	78.34	64.27	51.3	35	50	464041	0	0	2.5	1160102.5
	energy efficient new housing	LFO	LFO	11.55	8.48	44.3	60	50	173581	0	0	2.5	433952.5
	energy efficient new housing	electric	electric	44.81	40.08	17.6	60	50	149638	0	0	2	299276
	energy efficient new housing	NGS	NGS	78.34	54.23	51.3	60	50	464041	0	0	2.5	1160102.5
	building/envelope/ventilation/control	electric	electric	44.81	42.84	17.6	25	30	149638	0.02	2992.76	1.8	269348.4
	building envelope/ventilation/control retrofit	LFO	LFO	11.55	10.27	44.3	25	30	173581	0.02	3471.62	1.8	312445.8
	building envelope/ventilation/control retrofit	NGS	NGS	78.34	68.29	51.3	25	30	464041	0.02	9280.82	1.8	835273.8
	building/envelope/ventilation/control	electric	electric	44.81	41.26	17.6	45	30	149638	0.02	2992.76	1.8	269348.4
	building envelope/ventilation/control retrofit	LFO	LFO	11.55	9.25	44.3	45	30	173581	0.02	3471.62	1.8	312445.8
	building envelope/ventilation/control retrofit	NGS	NGS	78.34	60.26	51.3	45	30	464041	0.02	9280.82	1.8	835273.8
	thermally activated heat pump	electric	electric	44.81	42.05	17.6	35	50	149638	0	0	1	149638
	passive use of solar energy	LFO	LFO	11.55	9.50	44.3	40	50	173581	0	0	0.5	86790.5
	passive use of solar energy	electric	electric	44.81	41.66	17.6	40	50	149638	0	0	0.5	74819
	passive use of solar energy	NGS	NGS	78.34	62.26	51.3	40	50	464041	0	0	0.5	232020.5
	high efficiency furnace	LFO	NGS	11.55	10.27	44.3	25	30	173581	0.02	3471.62	2	347162
	increased burner efficiency	LFO	LFO	11.55	10.53	44.3	20	30	173581	0.045	7811.145	0.5	86790.5
	increased burner efficiency	NGS	NGS	78.34	70.30	51.3	20	30	464041	0.05	23202.05	0.4	185616.4
	convert heat source	LFO	electric	5.1	4.08	100	20	50	173581	0	0	1	173581
	convert heat source	NGS	electric	40.19	32.15	100	20	50	464041	0	0	1	464041
Water Heating	tank insulation/line insulation	electric	electric	44.81	43.29	13.6	25	50	149638	0	0	0.1	14963.8
	tank insulation/line insulation	LFO	LFO	11.55	10.91	22.1	25	50	173581	0	0	0.1	17358.1
	tank insulation/line insulation	NGS	NGS	78.34	74.61	23.8	20	50	464041	0	0	0.1	46404.1
	improved burner efficiency	LFO	LFO	11.55	11.04	22.1	20	20	173581	0.02	3471.62	0.4	69432.4
	improved burner efficiency	NGS	NGS	78.34	75.54	23.8	15	20	464041	0.01	4640.41	0.4	185616.4
	heat pump water heaters	electric	electric	44.81	42.68	13.6	35	20	149638	0	0	1	149638
	direct use of thermal solar heating	NGS	NGS	78.34	67.15	23.8	60	20	464041	0	0	3	1392123
	direct use of thermal solar heating	LFO	LFO	11.55	10.02	22.1	60	20	173581	0	0	3	520743
	direct use of thermal solar heating	electric	electric	44.81	41.76	13.6	50	20	149638	0	0	3	448914
	convert heat source	LFO	electric	2.55	1.79	100	30	20	173581	0	0	0.4	69432.4
	convert heat source	NGS	electric	18.68	13.08	100	30	20	464041	0	0	0.4	185616.4
RESIDENTIAL MULTI-UNIT DWELLING													
	air conditioning	electric	electric	44.81	44.80	0.2	15	20	65091	0	0	0.1	6509.1
	electric equipment improved motors	electric	electric	44.81	44.71	2.2	10	20	65091	0	0	0.01	650.91

	phase loading, load control and power	electric	electric	44.81	44.76	2.2	5	30	65091	0	0	0.02	1301.82
											0		
Space Heating	energy efficient new buildings	LFO	LFO	11.55	10.64	22.6	35	50	80778	0	0	0.8	64622.4
	energy efficient new buildings	electric	electric	44.81	42.96	11.8	35	50	65091	0	0	0.7	45563.7
	energy efficient new buildings	NGS	NGS	78.34	74.17	15.2	35	50	107821	0	0	0.8	86256.8
	energy efficient new buildings	LFO	LFO	11.55	10.24	22.6	50	50	80778	0	0	0.8	64622.4
	energy efficient new buildings	electric	electric	44.81	42.17	11.8	50	50	65091	0	0	0.7	45563.7
	energy efficient new buildings	NGS	NGS	78.34	72.39	15.2	50	50	107821	0	0	0.8	86256.8
	building envelope/ventilation/control	LFO	LFO	11.55	11.03	22.6	20	30	80778	0	0	0.7	56544.6
	building envelope/ventilation/control	NGS	NGS	78.34	75.96	15.2	20	30	107821	0	0	0.7	75474.7
	building envelope/ventilation/control	LFO	LFO	11.55	10.77	22.6	30	30	80778	0	0	0.7	56544.6
	building envelope/ventilation/control	NGS	NGS	78.34	74.77	15.2	30	30	107821	0	0	0.7	75474.7
	increased plant efficiency/cogeneration	LFO	LFO	11.55	11.16	22.6	15	40	80778	0	0	0.02	1615.56
	passive use of solar energy	LFO	LFO	11.55	10.24	22.6	50	50	80778	0	0	0.4	32311.2
	passive use of solar energy	electric	electric	44.81	42.17	11.8	50	50	65091	0	0	0.4	26036.4
	passive use of solar energy	NGS	NGS	78.34	72.39	15.2	50	50	107821	0	0	0.4	43128.4
	high efficiency furnace	LFO	NGS	11.55	11.16	22.6	15	40	80778	0	0	0.07	5654.46
	increased plant efficiency/cogeneration	NGS	NGS	78.34	76.55	15.2	15	40	107821	0	0	0.02	2156.42
	building/envelope/ventilation/control	electric	electric	44.81	43.75	11.8	20	50	65091	0	0	0.7	45563.7
	convert heat source	LFO	electric	2.6	2.08	100	20	50	80778	0	0	1	80778
	convert heat source	NGS	electric	11.91	9.53	100	20	50	107821	0	0	1	107821
	building envelope/ventilation/control	electric	electric	44.81	43.22	11.8	30	50	65091	0	0	0.7	45563.7
Water Heating	tank insulation/burner efficiency	LFO	LFO	11.55	11.29	11.3	20	30	80778	0	0	0.02	1615.56
	tank insulation/burner efficiency	NGS	NGS	78.34	77.35	8.4	15	30	107821	0	0	0.02	2156.42
	heat pump water heaters	electric	electric	44.81	44.29	5.8	20	30	65091	0	0	0.25	16272.75
	direct use of thermal solar heating	NGS	NGS	78.34	75.71	8.4	40	30	107821	0	0	0.5	53910.5
	direct use of thermal solar heating	electric	electric	44.81	43.12	5.8	65	30	65091	0	0	0.5	32545.5
	direct use of thermal solar heating	LFO	LFO	11.55	11.03	11.3	40	30	80778	0	0	0.5	40389
	convert heat source	LFO	electric	1.3	0.91	100	30	20	80778	0	0	0.4	32311.2
	convert heat source	NGS	electric	6.59	4.61	100	30	20	107821	0	0	0.4	43128.4
											0		
Lighting	high efficiency lighting	electric	electric	44.81	42.66	9.6	50	20	65091	0	0	0.15	9763.65

Sector	Name of Measure	Fuel Typ After Measure	CO2 Emission Factor Before Measure (kt/PJ)	CO2 Emission Before Measure (kt/yr)	CO2 Emission Factor After Measure (kt/PJ)	CO2 Emission After Measure (kt/yr)	Reduction In CO2 Yearly (kt)	Lifetime Reduction In Emissions (kt)
RESIDENTIAL HOUSING								
	user education/practices	NGS	49.68	3891.93	49.68	3502.74	389.19	19459.66
	user education/practices	electric	12.32	552.06	12.32	496.85	55.21	2760.30
	user education/practices	LFO	73.11	844.42	73.11	759.98	84.44	4222.10
	air conditioning	electric	12.32	552.06	12.32	552.02	0.04	0.77
	appliances & fixtures	electric	12.32	552.06	12.32	544.61	7.45	149.06
Space Heating	energy efficient new housing	LFO	73.11	844.42	73.11	713.49	130.93	6546.37
	energy efficient new housing	electric	12.32	552.06	12.32	518.05	34.01	1700.34
	energy efficient new housing	NGS	49.68	3891.93	49.68	3193.13	698.80	34939.81
Space Heating	energy efficient new housing	LFO	73.11	844.42	73.11	619.97	224.45	11222.35
	energy efficient new housing	electric	12.32	552.06	12.32	493.76	58.30	2914.87
	energy efficient new housing	NGS	49.68	3891.93	49.68	2693.99	1197.94	59896.82
	building/envelope/ventilation/control	electric	12.32	552.06	12.32	527.77	24.29	728.72
	building envelope/ventilation/control retrofit	LFO	73.11	844.42	73.11	750.90	93.52	2805.59
	building envelope/ventilation/control retrofit	NGS	49.68	3891.93	49.68	3392.79	499.14	14974.21
	building/envelope/ventilation/control	electric	12.32	552.06	12.32	508.34	43.72	1311.69
	building envelope/ventilation/control retrofit	LFO	73.11	844.42	73.11	676.09	168.34	5050.06
	building envelope/ventilation/control retrofit	NGS	49.68	3891.93	49.68	2993.48	898.45	26953.57
	thermally activated heat pump	electric	12.32	552.06	12.32	518.05	34.01	1700.34
	passive use of solar energy	LFO	73.11	844.42	73.11	694.79	149.63	7481.57
	passive use of solar energy	electric	12.32	552.06	12.32	513.19	38.86	1943.25
	passive use of solar energy	NGS	49.68	3891.93	49.68	3093.31	798.62	39931.21
	high efficiency furnace	NGS	73.11	844.42	49.68	510.26	334.17	10024.96
	increased burner efficiency	LFO	73.11	844.42	73.11	769.60	74.82	2244.47
	increased burner efficiency	NGS	49.68	3891.93	49.68	3492.62	399.31	11979.36
	convert heat source	electric	73.11	372.86	12.32	50.27	322.60	16129.77
	convert heat source	electric	49.68	1996.64	12.32	396.11	1600.53	80026.33
Water Heating	tank insulation/line insulation	electric	12.32	552.06	12.32	533.29	18.77	938.50
	tank insulation/line insulation	LFO	73.11	844.42	73.11	797.77	46.65	2332.71
	tank insulation/line insulation	NGS	49.68	3891.93	49.68	3706.68	185.26	9262.80
	improved burner efficiency	LFO	73.11	844.42	73.11	807.10	37.32	746.47
	improved burner efficiency	NGS	49.68	3891.93	49.68	3752.99	138.94	2778.84
	heat pump water heaters	electric	12.32	552.06	12.32	525.78	26.28	525.56
	direct use of thermal solar heating	NGS	49.68	3891.93	49.68	3336.16	555.77	11115.36
	direct use of thermal solar heating	LFO	73.11	844.42	73.11	732.45	111.97	2239.40
	direct use of thermal solar heating	electric	12.32	552.06	12.32	514.52	37.54	750.80
	convert heat source	electric	73.11	186.43	12.32	21.99	164.44	3288.79
	convert heat source	electric	49.68	928.02	12.32	161.10	766.93	15338.52
RESIDENTIAL MULTI-UNIT DWELLING								
	air conditioning	electric	12.32	552.06	12.32	551.89	0.17	3.31
	electric equipment improved motors	electric	12.32	552.06	12.32	550.84	1.21	24.29

	phase loading, load control and power	electric	12.32	552.06	12.32	551.45	0.61	18.22
Space Heating	energy efficient new buildings	LFO	73.11	844.42	73.11	777.63	66.79	3339.68
	energy efficient new buildings	electric	12.32	552.06	12.32	529.26	22.80	1140.00
	energy efficient new buildings	NGS	49.68	3891.93	49.68	3684.88	207.05	10352.54
Space Heating	energy efficient new buildings	LFO	73.11	844.42	73.11	749.00	95.42	4770.98
	energy efficient new buildings	electric	12.32	552.06	12.32	519.49	32.57	1628.57
	energy efficient new buildings	NGS	49.68	3891.93	49.68	3596.14	295.79	14789.34
	building envelope/ventilation/control	LFO	73.11	844.42	73.11	806.25	38.17	1145.03
	building envelope/ventilation/control	NGS	49.68	3891.93	49.68	3773.62	118.31	3549.44
	building envelope/ventilation/control	LFO	73.11	844.42	73.11	787.17	57.25	1717.55
	building envelope/ventilation/control	NGS	49.68	3891.93	49.68	3714.46	177.47	5324.16
	increased plant efficiency/cogeneration	LFO	73.11	844.42	73.11	815.79	28.63	1145.03
	passive use of solar energy	LFO	73.11	844.42	73.11	749.00	95.42	4770.98
	passive use of solar energy	electric	12.32	552.06	12.32	519.49	32.57	1628.57
	passive use of solar energy	NGS	49.68	3891.93	49.68	3596.14	295.79	14789.34
	high efficiency furnace	NGS	73.11	844.42	49.68	554.35	290.07	11602.74
	increased plant efficiency/cogeneration	NGS	49.68	3891.93	49.68	3803.20	88.74	3549.44
	building/envelope/ventilation/control	electric	12.32	552.06	12.32	539.03	13.03	651.43
	convert heat source	electric	73.11	190.09	12.32	25.63	164.46	8223.02
	convert heat source	electric	49.68	591.69	12.32	117.38	474.30	23715.19
	building envelope/ventilation/control	electric	12.32	552.06	12.32	532.52	19.54	977.14
Water Heating	tank insulation/burner efficiency	LFO	73.11	844.42	73.11	825.34	19.08	572.52
	tank insulation/burner efficiency	NGS	49.68	3891.93	49.68	3842.89	49.04	1471.15
	heat pump water heaters	electric	12.32	552.06	12.32	545.66	6.40	192.12
	direct use of thermal solar heating	NGS	49.68	3891.93	49.68	3761.16	130.77	3923.07
	direct use of thermal solar heating	electric	12.32	552.06	12.32	531.25	20.81	624.38
	direct use of thermal solar heating	LFO	73.11	844.42	73.11	806.25	38.17	1145.03
	convert heat source	electric	73.11	95.04	12.32	11.21	83.83	1676.64
	convert heat source	electric	49.68	327.39	12.32	56.83	270.56	5411.18
Lighting	high efficiency lighting	electric	12.32	552.06	12.32	525.56	26.50	529.98

Sector	Name of Measure	Fuel Typ After Measure	Fuel Price Before Measure (000's/PJ)	Fuel Cost Before Measure (000's/yr)	Incrementa Operating Cost Sector (000's/yr)	Fuel Price After Measure (000's/PJ)	Fuel Costs After Measure (000's/yr)	Incrementa Operating Costs (000's/yr)	Present Ne Operating Costs (000's)	Capital Costs Sector (000's)	Total Lifeime Cost of Measure (000's)	Payback of Measure (yrs)	Cost-Effective-ness ($/t)
RESIDENTIAL HOUSING													
	user education/practices	NGS	4664	365377.76	0	4664	328839.98	-36538	-303428	0.0	-303427.91	0.00	-15.59
	user education/practices	electric	15475	693434.75	0	15475	624091.28	-69343	-575863	0.0	-575862.78	0.00	-208.62
	user education/practices	LFO	7626	88080.3	0	7626	79272.27	-8808	-73146	0.0	-73146.27	0.00	-17.32
	air conditioning	electric	15475	693434.75	4489.14	15475	693386.21	4441	33169	14963.8	48132.61	3.37	62276.72
	appliances & fixtures	electric	15475	693434.75	0	15475	684073.38	-9361	-69924	14963.8	-54960.42	-1.60	-368.72
Space Heating	energy efficient new housing	LFO	7626	88080.3	0	7626	74423.45	-13657	-113413	433952.5	320539.21	-31.78	48.96
	energy efficient new housing	electric	15475	693434.75	0	15475	650719.17	-42716	-354731	299276.0	-55455.47	-7.01	-32.61
	energy efficient new housing	NGS	4664	365377.76	0	4664	299774.18	-65604	-544805	1160102.5	615297.70	-17.68	17.61
Space Heating	energy efficient new housing	LFO	7626	88080.3	0	7626	64668.56	-23412	-194423	433952.5	239529.71	-18.54	21.34
	energy efficient new housing	electric	15475	693434.75	0	15475	620208.04	-73227	-608111	299276.0	-308835.10	-4.09	-105.96
	energy efficient new housing	NGS	4664	365377.76	0	4664	252914.49	-112463	-933951	1160102.5	226151.41	-10.32	3.78
	building/envelope/ventilation/control	electric	15475	693434.75	2992.76	15475	662923.62	-27518	-221666	269348.4	47682.88	-9.79	65.43
	building envelope/ventilation/control retro	LFO	7626	88080.3	3471.62	7626	78325.41	-6283	-50613	312445.8	261832.88	-49.73	93.33
	building envelope/ventilation/control retro	NGS	4664	365377.76	9280.82	4664	318518.06	-37579	-302705	835273.8	532569.03	-22.23	35.57
	building/envelope/ventilation/control	electric	15475	693434.75	2992.76	15475	638514.72	-51927	-418284	269348.4	-148935.33	-5.19	-113.54
	building envelope/ventilation/control retro	LFO	7626	88080.3	3471.62	7626	70521.49	-14087	-113475	312445.8	196970.91	-22.18	39.40
	building envelope/ventilation/control retro	NGS	4664	365377.76	9280.82	4664	281030.30	-75067	-604676	835273.8	230598.24	-11.13	8.56
	thermally activated heat pump	electric	15475	693434.75	0	15475	650719.17	-42716	-354731	149638.0	-205093.47	-3.50	-120.62
	passive use of solar energy	LFO	7626	88080.3	0	7626	72472.47	-15608	-129615	86790.5	-42824.69	-5.56	-5.72
	passive use of solar energy	electric	15475	693434.75	0	15475	644616.94	-48818	-405407	74819.0	-330588.40	-1.53	-170.12
	passive use of solar energy	NGS	4664	365377.76	0	4664	290402.24	-74976	-622634	232020.5	-390613.56	-3.09	-9.78
	high efficiency furnace	NGS	7626	88080.3	3471.62	4664	47903.19	-36705	-295670	347162.0	51492.49	-9.46	5.14
	increased burner efficiency	LFO	7626	88080.3	7811.145	7626	80276.39	7	58	86790.5	86848.74	12003.52	38.69
	increased burner efficiency	NGS	4664	365377.76	23202.05	4664	327890.00	-14286	-115074	185616.4	70542.39	-12.99	5.89
	convert heat source	electric	7626	38892.6	0	15475	63138.00	24245	201346	173581.0	374926.89	7.16	23.24
	convert heat source	electric	4664	187446.16	0	15475	497552.20	310106	2575275	464041.0	3039316.14	1.50	37.98
Water Heating	tank insulation/line insulation	electric	15475	693434.75	0	15475	669857.97	-23577	-195793	14963.8	-180829.55	-0.63	-192.68
	tank insulation/line insulation	LFO	7626	88080.3	0	7626	83213.86	-4866	-40413	17358.1	-23055.22	-3.57	-9.88
	tank insulation/line insulation	NGS	4664	365377.76	0	4664	347985.78	-17392	-144432	46404.1	-98027.58	-2.67	-10.58
	improved burner efficiency	LFO	7626	88080.3	3471.62	7626	84187.15	-422	-3149	69432.4	66283.81	-164.72	88.80
	improved burner efficiency	NGS	4664	365377.76	4640.41	4664	352333.77	-8404	-62770	185616.4	122846.36	-22.09	44.21
	heat pump water heaters	electric	15475	693434.75	0	15475	660427.26	-33007	-246548	149638.0	-96909.62	-4.53	-184.39
	direct use of thermal solar heating	NGS	4664	365377.76	0	4664	313201.82	-52176	-389725	1392123.0	1002397.73	-26.68	90.18
	direct use of thermal solar heating	LFO	7626	88080.3	0	7626	76400.85	-11679	-87239	520743.0	433504.02	-44.59	193.58
	direct use of thermal solar heating	electric	15475	693434.75	0	15475	646281.19	-47154	-352211	448914.0	96703.12	-9.52	128.80
	convert heat source	electric	7626	19446.3	0	15475	27622.88	8177	61074	69432.4	130506.87	8.49	39.68
	convert heat source	electric	4664	87123.52	0	15475	202351.10	115228	860686	185616.4	1046302.31	1.61	68.21
RESIDENTIAL MULTI-UNIT DWELLING													
	air conditioning	electric	15475	693434.75	0	15475	693226.72	-208	-1554	6509.1	4955.23	-31.29	1495.98
	electric equipment improved motors	electric	15475	693434.75	0	15475	691909.19	-1526	-11395	650.9	-10744.15	-0.43	-442.32

	phase loading, load control and power	electric	15475	693434.75	0	15475	692671.97	-763	-6144	1301.8	-4842.50	-1.71	-265.81
					0								
Space Heating	energy efficient new buildings	LFO	7626	88080.3	0	7626	81113.15	-6967	-57859	64622.4	6763.70	-9.28	2.03
	energy efficient new buildings	electric	15475	693434.75	0	15475	664795.89	-28639	-237831	45563.7	-192267.63	-1.59	-168.66
	energy efficient new buildings	NGS	4664	365377.76	0	4664	345939.66	-19438	-161424	86256.8	-75166.85	-4.44	-7.26
Space Heating	energy efficient new buildings	LFO	7626	88080.3	0	7626	78127.23	-9953	-82655	64622.4	-18032.89	-6.49	-3.78
	energy efficient new buildings	electric	15475	693434.75	0	15475	652522.10	-40913	-339759	45563.7	-294195.34	-1.11	-180.65
	energy efficient new buildings	NGS	4664	365377.76	0	4664	337609.05	-27769	-230605	86256.8	-144348.41	-3.11	-9.76
	building envelope/ventilation/control	LFO	7626	88080.3	0	7626	84099.07	-3981	-32070	56544.6	24475.06	-14.20	21.37
	building envelope/ventilation/control	NGS	4664	365377.76	0	4664	354270.28	-11107	-89473	75474.7	-13998.13	-6.79	-3.94
	building envelope/ventilation/control	LFO	7626	88080.3	0	7626	82108.46	-5972	-48104	56544.6	8440.30	-9.47	4.91
	building envelope/ventilation/control	NGS	4664	365377.76	0	4664	348716.53	-16661	-134209	75474.7	-58734.54	-4.53	-11.03
	increased plant efficiency/cogeneration	LFO	7626	88080.3	0	7626	85094.38	-2986	-24615	1615.6	-22999.72	-0.54	-20.09
	passive use of solar energy	LFO	7626	88080.3	0	7626	78127.23	-9953	-82655	32311.2	-50344.09	-3.25	-10.55
	passive use of solar energy	electric	15475	693434.75	0	15475	652522.10	-40913	-339759	26036.4	-313722.64	-0.64	-192.64
	passive use of solar energy	NGS	4664	365377.76	0	4664	337609.05	-27769	-230605	43128.4	-187476.81	-1.55	-12.68
	high efficiency furnace	NGS	7626	88080.3	0	4664	52043.03	-36037	-297083	5654.5	-291428.71	-0.16	-25.12
	increased plant efficiency/cogeneration	NGS	4664	365377.76	0	4664	357047.15	-8331	-68676	2156.4	-66519.29	-0.26	-18.74
	building/envelope/ventilation/control	electric	15475	693434.75	0	15475	677069.69	-16365	-135904	45563.7	-90339.92	-2.78	-138.68
	convert heat source	electric	7626	19827.6	0	15475	32188.00	12360	102647	80778.0	183424.92	6.54	22.31
	convert heat source	electric	4664	55548.24	0	15475	147445.80	91898	763163	107821.0	870984.15	1.17	36.73
	building envelope/ventilation/control	electric	15475	693434.75	0	15475	668887.16	-24548	-203855	45563.7	-158291.73	-1.86	-161.99
Water Heating	tank insulation/burner efficiency	LFO	7626	88080.3	0	7626	86089.69	-1991	-16035	1615.6	-14419.21	-0.81	-25.19
	tank insulation/burner efficiency	NGS	4664	365377.76	0	4664	360774.00	-4604	-37084	2156.4	-34927.71	-0.47	-23.74
	heat pump water heaters	electric	15475	693434.75	0	15475	685390.91	-8044	-64795	16272.8	-48521.89	-2.02	-252.56
	direct use of thermal solar heating	NGS	4664	365377.76	0	4664	353101.07	-12277	-98891	53910.5	-44980.52	-4.39	-11.47
	direct use of thermal solar heating	electric	15475	693434.75	0	15475	667292.26	-26142	-210583	32545.5	-178037.07	-1.24	-285.14
	direct use of thermal solar heating	LFO	7626	88080.3	0	7626	84099.07	-3981	-32070	40389.0	8319.46	-10.14	7.27
	convert heat source	electric	7626	9913.8	0	15475	14082.25	4168	31136	32311.2	63447.20	7.75	37.84
	convert heat source	electric	4664	30735.76	0	15475	71386.18	40650	303636	43128.4	346764.38	1.06	64.08
Lighting	high efficiency lighting	electric	15475	693434.75	0	15475	660149.88	-33285	-248619	9763.7	-238855.80	-0.29	-450.69

APPENDIX B

CO_2 EMISSION FACTORS

Appendix B

CO_2 Emission Factors

		t CO_2 per TJ
Pulp liquor		107.38
Wood waste		81.47
Fuel wood		81.47
Forest fires		81.47
Coal		90.00
Light fuel oil		73.11
Heavy fuel oil		71.54
Diesel oil		70.69
LPG		70.22
Natural gas		49.68
Transportation	gasoline	67.98
	methanol	66.62
	diesel	60.50
	propane	57.78
	CNG	57.10
	ethanol	23.79
Electricity		12.32

Source: B.H. Levelton (1990); Transportation: see Appendix A.C; Electricity: The ARA Consulting Group based on B.H. Levelton (1990) emission factors and EMPR (1991) energy demand.

APPENDIX C

ENERGY & EMISSIONS FORECASTS

Appendix C

Energy Demand and Emissions Inventory

The basic CO_2 inventory and forecasts used in this analysis are those presented in the 1988 inventory by B.H. Levelton and Associates (1990). However, the base year was revised to 1989 and forecasts updated based on the latest projections by the provincial government's Ministry of Energy, Mines and Petroleum Resources (EMPR, 1991).

Exhibit C.1 provides a reconciliation of the energy and emission inventory and forecasts from the two sources. Components of the updated figures (see columns titled "EMPR" in Exhibit C.1) were based on the Levelton study where EMPR estimates were not available (e.g., process sources, solid waste, slash burnings).

Exhibit C.2 presents the EMPR forecast provided to the ARA Consulting Group as a basis for the revisions.

Exhibit C.1: Comparision of Energy Demand Forecasts: BH Levelton (1990) and EMPR (1991)

GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	PETAJOULES 1988 BHL	PETAJOULES 1988 EMPR	PETAJOULES 1989 EMPR	PETAJOULES 2005 BHL	PETAJOULES 2005 EMPR	EMISSION FACTOR kt CO2/PJ	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 BHL	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 EMPR	ESTIMATED CO2 EMMISSIONS (ktCO2) 1989 EMPR	ESTIMATED CO2 EMMISSIONS (ktCO2) 2005 BHL	ESTIMATED CO2 EMMISSIONS (ktCO2) 2005 EMPR
PROCESS SOURCES														
	LIME KILNS									129.04	129.04	136.78	243.57	243.57
	CEMENT LIME KILNS									722.64	722.64	737.52	975.69	975.69
	PULP&PAPER LIME KILNS									1638.10	1638.10	1650.11	1842.21	1842.21
	METHANOL/AMMONIA			16.83	16.83	17.27	24.37	24.37	2.75	46.19	46.20	48.59	66.89	66.90
	MISC. CHEM. IND.									17.50	17.50	17.96	25.34	25.34
	ALUMINUM SMELTING									650.00	650.00	650.00	650.00	650.00
	CO BOILERS (PETROLEUM REF.)									35.00	35.00	34.25	22.25	22.25
	CO2 FROM NATURAL GAS									0.54	0.54	0.55	0.67	0.67
		SUM_1		16.83	16.83	17.27	24.37	24.37		3239.01	3239.02	3275.76	3826.62	3826.63
STATIONARY FUEL COMBUSTION														
	GAS UTILITIES													
			N.G.	48.52	48.52	49.19	59.86	59.86	49.68	2410.47	2410.47	2443.76	2973.84	2973.84
		SUM_2.1		48.52	48.52	49.19	59.86	59.86		2410.47	2410.47	2443.76	2973.84	2973.84
	POWER GENERATION													
			N.G.	4.52	4.18	47.66	32.41	52.86	49.68	224.55	207.66	2367.75	1609.98	2626.08
			DFO	2.52	2.52	2.55	0.43	3.03	70.69	178.14	178.14	180.26	30.68	214.19
			HFO	1.06	2.89	3.12	1.53	4.20	71.54	75.83	206.75	223.20	109.63	300.47
			PULP LIQ.	3.96	5.48	6.12	5.73	6.79	107.38	425.22	588.44	657.17	614.75	729.11
			COAL		0.00	0.00	36.38	0.00	90.00	0.00	0.00	0.00	3274.02	0.00
			HOG	2.81	2.98	3.31	5.04	13.57	81.47	228.93	242.78	269.67	410.61	1105.55
		SUM_2.2		14.87	18.05	62.76	81.52	80.45		1132.68	1423.77	3698.04	6049.67	4975.40
	RESIDENTIAL/AGRICULTURAL													
			N.G.	71.78	71.78	78.34	92.24	119.34	49.68	3566.03	3566.03	3891.93	4582.58	5928.81
			C&C	0.01	0.01	0.01	0.01	0.00	90.00	0.90	0.90	0.54	1.26	0.00
			HFO	0.00	0.00	0.00	0.24	0.00	71.54	0.00	0.00	0.00	17.17	0.00
			LFO	11.69	11.69	11.55	15.82	3.42	73.11	854.66	854.66	844.42	1156.67	250.04
			LPG	1.37	1.37	1.34	3.74	0.56	70.22	96.20	96.20	94.09	262.76	39.32
			DFO	1.60	1.60	3.29	6.48	3.84	70.69	113.10	113.10	232.57	458.21	271.45
			RENEW.	0.00	0.00	0.00	7.65	0.00	81.47	0.00	0.00	0.00	623.57	0.00
			KEROSENE											
			FARMMOTGASOLINE											
		SUM_2.3		86.45	86.45	94.53	126.20	127.16		4630.89	4630.89	5063.56	7102.23	6489.62

Exhibit C.1: Comparision of Energy Demand Forecasts: BH Levelton (1990) and EMPR (1991)

GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	PETAJOULES 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR	EMISSION FACTOR kt CO2/PJ	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR
	COMMERCIAL/PUBLIC ADMIN													
			N.G.	34.58	34.58	34.58	64.07	64.07	49.68	1717.93	1717.93	1717.93	3183.00	3183.00
			HFO	1.09	1.09	1.09	4.65	4.65	71.54	77.98	77.98	77.98	332.66	332.66
			LFO	5.56	5.56	5.56	3.79	3.79	73.11	406.49	406.49	406.49	277.09	277.09
			DFO	4.91	4.91	4.91	4.78	4.78	70.69	347.09	347.09	347.09	338.04	338.04
			LPG	2.83	2.83	2.83	5.31	5.31	70.22	198.72	198.72	198.72	372.87	372.87
			KEROSENE											
			AVIATION GAS											
			AVIATION TURBO											
		SUM_2.4		48.97	48.97	48.97	82.60	82.60		2748.22	2748.22	2748.22	4503.65	4503.65
	INDUSTRIAL													
		PULP&PAPER												
			N.G.	23.52	23.52	23.41	31.76	45.16	49.68	1168.47	1168.47	1163.01	1577.84	2243.55
			C&C	0.25	0.25	0.09	3.32	0.23	90.00	22.50	22.50	8.46	298.80	20.70
			HFO	21.93	20.09	23.39	19.78	18.62	71.54	1568.87	1437.24	1673.32	1415.06	1332.07
			LPG	0.31	0.31	0.33	0.17	0.39	70.22	21.77	21.77	22.89	11.94	27.39
			DFO	0.47	0.47	0.50	0.35	0.63	70.69	33.22	33.22	35.56	24.74	44.53
			HOG	45.44	45.32	45.98	60.89	53.52	81.47	3702.00	3692.22	3745.58	4960.71	4360.27
			PULP LIQ.	132.71	131.18	132.42	133.63	141.68	107.38	14250.40	14086.11	14219.37	14349.19	15213.60
			OTHER	0.75	0.75	0.71	1.32	1.45	0.00	0.00	0.00	0.00	0.00	0.00
			SUM_2.5.1	225.38	221.89	226.83	251.22	261.68		20767.23	20461.53	20868.19	22638.27	23242.12
		WOOD PROD.												
			N.G.	13.91	13.91	14.05	9.72	15.22	49.68	691.05	691.05	698.10	482.69	756.13
			HFO	0.09	0.00	0.00	0.05	0.00	71.54	6.44	0.00	0.00	3.22	0.00
			LFO	0.13	0.13	0.10	0.08	0.02	73.11	9.50	9.50	6.95	5.92	1.46
			LPG	0.75	0.75	0.60	0.25	0.15	70.22	52.67	52.67	42.20	17.41	10.53
			DFO	9.77	2.00	1.84	3.09	0.43	70.69	690.64	141.38	130.07	218.64	30.40
			HOG	22.47	22.42	22.74	32.82	28.84	81.47	1830.63	1826.56	1852.38	2673.68	2349.59
			SUM_2.5.2	47.12	39.21	39.33	46.00	44.66		3280.93	2721.16	2729.70	3401.57	3148.12
		PRIMARY METALS												
			N.G.	2.14	2.41	2.03	4.62	2.31	49.68	106.32	119.73	100.75	229.52	114.76
			HFO	0.04	0.04	0.04	0.13	0.01	71.54	2.86	2.86	3.08	9.23	0.72
			LFO	0.06	0.06	0.05	0.13	0.02	73.11	4.39	4.39	3.73	9.65	1.46

Exhibit C.1: Comparision of Energy Demand Forecasts: BH Levelton (1990) and EMPR (1991)

GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	PETAJOULES 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR	EMISSION FACTOR kt CO2/PJ	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR
			DFO	0.10	0.10	0.10	0.21	0.03	70.69	7.07	7.07	6.72	15.06	2.12
			LPG	0.01	0.00	0.00	0.01	0.00	70.22	0.70	0.00	0.00	0.91	0.00
			SUM_2.5.3	2.35	2.61	2.22	5.11	2.37		121.33	134.05	114.27	264.37	119.06
		CHEM. IND.												
			N.G.	4.31	4.31	4.55	5.32	4.53	49.68	214.12	214.12	226.19	264.30	225.05
			HFO	0.61	0.61	0.64	0.32	0.45	71.54	43.64	43.64	45.79	22.89	32.19
			LFO	0.04	0.04	0.04	0.07	0.03	73.11	2.92	2.92	2.71	5.12	2.19
			DFO	0.00	0.00	0.00	0.04	0.00	70.69	0.00	0.00	0.00	2.83	0.00
			SUM_2.5.4	4.96	4.96	5.23	5.75	5.01		260.68	260.68	274.68	295.14	259.44
		NON-MET. MINERALS												
			N.G.	2.72	2.72	2.71	1.15	3.37	49.68	135.13	135.13	134.73	57.33	167.42
			C&C	0.95	0.95	0.94	11.00	1.15	90.00	85.50	85.50	84.78	990.00	103.50
			HFO	0.00	0.00	0.00	1.21	0.00	71.54	0.00	0.00	0.00	86.42	0.00
			LFO	0.00	0.00	0.00	0.10	0.00	73.11	0.00	0.00	0.00	7.09	0.00
			DFO	0.09	0.09	0.09	1.69	0.11	70.69	6.36	6.36	6.57	119.61	7.78
			LPG	0.01	0.01	0.01	0.08	0.01	70.22	0.70	0.70	0.84	5.48	0.70
			SUM_2.5.5	3.77	3.77	3.76	15.23	4.64		227.69	227.69	226.93	1265.93	279.40
		PETROLEUM REF.												
			DFO	0.16	0.16	0.47	0.69	0.39	70.69	11.31	11.31	33.51	48.49	27.57
			HFO	0.25	0.25	0.34	0.11	0.39	71.54	17.89	17.89	24.47	8.01	27.90
			LFO	0.01	0.01	0.02	0.04	0.01	70.69	0.71	0.71	1.48	2.54	0.71
			MOTOR GAS	0.01	0.01	0.23	0.30	0.12	67.98	0.68	0.68	15.30	20.39	8.16
			PETR. COKE	1.90	1.90	1.89	0.74	1.90	94.42	179.40	179.40	178.36	70.15	179.40
			STILL GAS	17.25	17.25	17.25	4.57	11.85	59.84	1032.24	1032.24	1032.30	273.17	709.10
			N.G.	1.25	1.25	0.48	5.73	0.56	49.68	62.10	62.10	23.80	284.52	27.82
			SUM_2.5.6	20.83	20.83	20.68	12.17	15.22		1304.32	1304.32	1309.21	707.29	980.66
		OTHER MFG.												
			N.G.	14.59	16.76	16.61	14.01	29.37	49.68	724.83	832.64	825.09	695.77	1459.10
			C&C	2.54	0.00	0.00	0.01	0.00	90.00	228.60	0.00	0.00	0.90	0.00
			HFO	0.17	0.17	0.17	0.38	0.10	71.54	12.16	12.16	12.38	26.97	7.15
			LFO	0.23	0.23	0.24	0.16	0.19	73.11	16.82	16.82	17.62	11.62	13.89
			DFO	0.72	0.72	0.74	0.32	1.17	70.69	50.90	50.90	52.59	22.41	82.71

Exhibit C.1: Comparision of Energy Demand Forecasts: BH Levelton (1990) and EMPR (1991)

GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	PETAJOULES 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR	EMISSION FACTOR kt CO2/PJ	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR
			LPG	0.26	0.27	0.28	0.11	0.44	70.22	18.26	18.96	19.52	7.93	30.90
			SUM_2.5.7	18.51	18.15	18.04	14.98	31.27		1051.56	931.47	927.20	765.61	1593.75
		MINING												
			N.G.	6.88	6.88	5.41	2.02	7.83	49.68	341.80	341.80	268.87	100.20	388.99
			C&C	4.01	4.01	5.11	8.39	6.38	90.00	360.90	360.90	459.99	755.46	574.20
			HFO	0.00	0.00	0.00	4.83	0.00	71.54	0.00	0.00	0.00	345.25	0.00
			LFO	0.01	0.00	0.00	0.41	0.00	73.11	0.73	0.00	0.00	29.90	0.00
			DFO	10.36	10.36	7.55	27.96	5.02	70.69	732.35	732.35	533.99	1976.70	354.86
			LPG	0.37	0.37	0.28	0.51	0.19	70.22	25.98	25.98	19.45	35.74	13.34
			SUM_2.5.8	21.63	21.62	18.35	44.12	19.42		1461.76	1461.03	1282.30	3243.27	1331.40
		OTHER IND.												
			N.G.	11.49	12.08	5.42	1.07	6.87	49.68	570.82	600.13	269.27	53.26	341.30
			HFO		0.00	0.10	2.32	0.10	71.54	0.00	0.00	6.87	165.97	7.15
			LFO	1.21	1.21	1.37	1.36	1.37	73.11	88.46	88.46	100.16	99.43	100.16
			DFO	4.36	4.36	12.13	18.92	12.13	70.69	308.21	308.21	857.33	1337.10	857.47
			KEROSENE							0.00	0.00	0.00	0.00	0.00
			LPG							0.00	0.00	0.00	0.00	0.00
			C&C	0.00	2.54	2.54	0.00	2.54	90.00	0.00	228.60	228.60	0.00	228.60
			RENEW.							0.00	0.00	0.00	0.00	0.00
			SUM_2.5.9	17.06	20.19	21.55	23.67	23.01		967.49	1225.41	1462.22	1655.76	1534.69
		SUM_2.5		361.61	353.23	355.99	418.24	407.28		29443.01	28727.34	29194.71	34237.20	32488.62
	FUEL WOO	SUM_2.6		8.19	8.19	8.19	8.19	8.19	81.47	667.29	667.24	667.24	667.24	667.24
		SUM_2		568.61	563.41	619.63	776.61	765.54		41032.56	40607.93	43815.52	55533.84	52098.38
MOBILE COMBUSTION														
	ROAD VEHICLES													
		GASOLINE												
			LDGV	76.32		79.14	102.90		67.98	5188.23	0.00	5379.94	6994.80	0.00
			LDGT 1	10.51		10.90	14.17		67.98	714.61	0.00	740.98	963.34	0.00
			LDGT 2	26.36		27.33	35.54		67.98	1792.02	0.00	1857.89	2415.81	0.00
			HDGV	7.58		7.86	10.22		67.98	515.36	0.00	534.32	694.82	0.00

Exhibit C.1: Comparision of Energy Demand Forecasts: BH Levelton (1990) and EMPR (1991)

GROUP	SECTOR	SUB-SECTOR	FUEL TYPE		PETAJOULES 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR	EMISSION FACTOR kt CO2/PJ	ESTIMATED CO2 EMMISSIONS (ktCO2) 1988 BHL	1988 EMPR	1989 EMPR	2005 BHL	2005 EMPR
SOLID WASTE DISPOSAL															
	MUNICIPAL			(kt)	270.00	*270.00*	*284.00*	500.00	*500.00*	0.90	243.38	*243.38*	*256.00*	450.70	*450.70*
	LANDFILL GAS			(kt)	1860.00	*1860.00*	*1818.00*	1160.00	*1160.00*	0.17	310.62	*310.62*	*303.61*	193.72	*193.72*
	INDUSTRIAL&iNSTITUTIONAL			(kt)	15.80	*15.80*	*16.00*	19 79	*19.79*	0.90	14.24	*14.24*	*14.42*	17.84	*17.84*
	WOOD WASTE		HOG	(kt)	108.36	*108.36*	*106.77*	81.27	*81.27*	81.47	8828.09	*8828.09*	*8698.55*	6621.07	*6621.07*
		SUM_4			2254.16	*2254.16*	2224.77	1761.06	*1761.06*		9396.33	*9396.33*	*9272.58*	7283.33	*7283.33*
OPEN BURNING															
	PRESCRIBED BURNING										13300.00	*13300.00*	13065.00	9300.00	*9300.00*
	WILD FIRE										350.00	4300.00	4300.00	4300.00	4300.00
		SUM_5			0.00	0.00	0.00	0.00	0.00		13300.00	*13300.00*	*13065.00*	9300.00	*9300.00*
GRAND SUM OF ALL SECTIONS *(excluding wildfires)*					3091.69	3091.80	3134.85	2892.92	2872.16		*84379.99*	84329.05	*88318.13*	*98708.05*	*94750.18*

* Data displayed in italics represents energy use and emissions based on B.H. Levelton (1990) because data not available from EMPR.

Sources: B.H. Levelton (1990); Energy, Mines & Petroleum Resources (1991).

Exhibit C2: EMPR Energy Demand Forecast

Record#	MNEMONIC	TITLE	SECTOR	FUEL	DESCRIPT	UNITS
1	DELCRES	Elec:Residential	RES	ELC	SECONDARY REQTS; ELECTRICITY; RESIDENTIAL	PJ
2	DLFORES	LFO:Residential	RES	LFO	SECONDARY REQTS; LIGHT FUEL OIL; AGRICULTURAL	PJ
3	DLPGRES	LPGs:Residential	RES	LPG	SECONDARY REQTS; LPGs; RESIDENTIAL	PJ
4	DNGSRES	Ngs:Residential	RES	NGS	SECONDARY REQTS; NATURAL GAS; RESIDENTIAL	PJ
5	DDFORES	DFO:Residential	RES	DFO	SECONDARY REQTS; DIESEL FUEL; AGRICULTURE	PJ
6	DCACRES	Coal:Residential	RES	CAC	SECONDARY REQTS; COKE & COAL; RESIDENTIAL	PJ
7	DAVTAIR	Air:Jet Fuel	AIR	AVT	SECONDARY REQTS; AVIATION TURBO; AIR	PJ
8	DAVGAIR	Air:Aviation Gasoline	AIR	AVG	SECONDARY REQTS; AVIATION GASOLINE; AIR	PJ
9	DDFOMAR	Marine:DFO	MAR	DFO	SECONDARY REQTS; DIESEL FUEL; MARINE	PJ
10	DHFOMAR	Marine:HFO	MAR	HFO	SECONDARY REQTS; HEAVY FUEL OIL; MARINE	PJ
11	DDFORAL	Rail:DFO	RAL	DFO	SECONDARY REQTS; DIESEL FUEL; RAIL	PJ
12	DELCTRN	Elec:Transport	TRN	ELC	END USE; ELECTRICITY; TRANSPORTATION; TOTAL	PJ
13	DDFORDD	Road:DFO	ROD	DFO	SECONDARY REQTS; DIESEL FUEL; ROAD	PJ
14	DMOGROD	Road:Gasoline	ROD	MOG	SECONDARY REQTS; MOTOR GASOLINE; ROAD	PJ
15	DLPGROD	Road:LPGs	ROD	LPG	SECONDARY REQTS; LPGs; ROAD TRANSPORT	PJ
16	DNGSTRN	Ngs:Transport	TRN	NGS	END USE; NATURAL GAS; TRANSPORTATION; TOTAL	PJ
17	DHFOPMT		PMT	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PRIMARY METALS	PJ
18	DHFOCHE		CHE	HFO	SECONDARY REQTS; HEAVY FUEL OIL; CHEMICALS	PJ
19	DHFOXMA		XMA	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER MANUFACTUR	PJ
20	DHFOPAPSE	HFO:Pulp&Paper	PAP	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PULP&PAPER	PJ
21	DLFOWOD		WOD	LFO	SECONDARY REQTS; LIGHT FUEL OIL; WOOD PRODUCTS	PJ
22	DHFOXIN		XIN	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER INDUSTRIAL	PJ
23	DHFOSUP		SUP	HFO	PRODUCER REQTS; HEAVY FUEL OIL	PJ
24	GHFOPAP		PAP	HFO	USED TO GENERATE ELEC; HEAVY FUEL OIL; PULP&PAPER	PJ
25	DLFOPMT		PMT	LFO	SECONDARY REQTS; LIGHT FUEL OIL; PRIMARY METALS	PJ
26	DLFOCHE		CHE	LFO	SECONDARY REQTS; LIGHT FUEL OIL; CHEMICALS	PJ
27	DLFOXMA		XMA	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER MANUFACTUR	PJ
28	DDFOPAPSE	DFO:Pulp&Paper	PAP	DFO	SECONDARY REQTS; DIESEL FUEL; PULP&PAPER	PJ
29	DLFOXIN		XIN	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER INDUSTRIAL	PJ
30	DLFOSUP		SUP	LFO	PRODUCER REQTS; LIGHT FUEL OIL	PJ
31	DDFOWOD		WOD	DFO	SECONDARY REQTS; DIESEL FUEL; WOOD PRODUCTS	PJ
32	DDFOPMT		PMT	DFO	SECONDARY REQTS; DIESEL FUEL; PRIMARY METALS	PJ
33	DDFONMT		NMT	DFO	SECONDARY REQTS; DIESEL FUEL; NON-METALLIC	PJ
34	DDFOXMA		XMA	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER MANUFACTURING	PJ
35	DDFOMINSE		MIN	DFO	SECONDARY REQTS; DIESEL FUEL; MINING	PJ
36	DLPGPAPSE	LPGs:Pulp&Paper	PAP	LPG	SECONDARY REQTS; LPGs; PULP&PAPER	PJ
37	DDFOXIN		XIN	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER INDUSTRIAL	PJ
38	DDFOSUP		REF	DFO	PRODUCER REQTS; DIESEL FUEL	PJ
39	GDFOTOT	DFO:Converted to Elc	SUP	DFO	USED TO GENERATE ELEC; DIESEL FUEL; TOTAL	PJ
40	DLPGWOD		WOD	LPG	SECONDARY REQTS; LPGs; WOOD PRODUCTS	PJ
41	DLPGNMT		NMT	LPG	SECONDARY REQTS; LPGs; NON-METALLIC	PJ
42	DLPGXMA		XMA	LPG	SECONDARY REQTS; LPGs; OTHER MANUFACTURING	PJ
43	DLPGMIN		MIN	LPG	SECONDARY REQTS; LPGs; MINING	PJ
44	DLPGXIN		XIN	LPG	SECONDARY REQTS; LPGs; OTHER INDUSTRIAL	PJ
45	DMOGSUP		REF	MOG	PRODUCER REQTS; MOTOR GASOLINE	PJ
46	DSGSSUP		REF	SGS	PRODUCER REQTS; STILL GAS	PJ
47	DLPGSUP	RPPs:Ngs Plant Own Use	NGS	LPG	PRODUCER REQTS; LPGs	PJ
48	DPCKSUP		SUP	PCK	PRODUCER REQTS; PETROLEUM COKE	PJ
49	DLGRNON		NON	LGR	SECONDARY REQTS; LUBES & GREASES; NON-ENERGY USES	PJ
50	DPCKNON		NON	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-ENERGY	PJ
51	DPCKNMT		NMT	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-METALLIC	PJ
52	DNGSXMA	Ngs:Other Manf	XMA	NGS	SECONDARY REQTS; NATURAL GAS; OTHER MANUFACTUR	PJ
53	DNENSUP		SUP	NEN	PRODUCER REQTS; NON-ENERGY PRODUCTS	PJ
54	DASPNON		NON	ASP	SECONDARY REQTS; ASPHALT; CONVERTED @ 44.46TJ=Ml	PJ
55	DOTHNON		NON	OTH	SECONDARY REQTS; OTHER NON-ENERGY	PJ
56	DNGSWOD	Ngs:Wood	WOD	NGS	SECONDARY REQTS; NATURAL GAS; WOOD PRODUCTS	PJ
57	DNGSCHE	Ngs:Chemicals	CHE	NGS	SECONDARY REQTS; NATURAL GAS; CHEMICALS	PJ
58	DNGSXINSE	Ngs:Other Ind	XIN	NGS	SECONDARY REQTS; NATURAL GAS; OTHER IND	PJ
59	DNGSPAPSE	Ngs:Pulp&Paper	PAP	NGS	SECONDARY REQTS; NATURAL GAS; PULP&PAPER	PJ
60	DNGSPMT	Ngs:Primary Metals	PMT	NGS	SECONDARY REQTS; NATURAL GAS; PRIMARY METALS	PJ
61	DNGSNMT	Ngs:Cement	NMT	NGS	SECONDARY REQTS; NATURAL GAS; NON-METALLIC	PJ
62	DNGSPCM	Ngs:Petrochemicals	PCM	NGS	FEEDSTOCK REQTS; NATURAL GAS	PJ
63	DNGSREF	Ngs:Refineries	REF	NGS	SECONDARY REQTS; NATURAL GAS; REFINERY	PJ
64	DNGSMIN	Ngs:Mining	MIN	NGS	SECONDARY REQTS; NATURAL GAS; MINING	PJ

65	GNGSPAP		PAP	NGS	USED TO GENERATE ELEC; NATURAL GAS; PULP&PAPER	PJ
66	GNGSBCH	Ngs:To Elc by Utl	SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; BC HYDRO	PJ
67	DNGSPIP	Ngs:Pipelines&Losses	SUP	NGS	PIPELINE USE; NATURAL GAS	PJ
68	DCACNMT	Coal:Cement	NMT	CAC	SECONDARY REQTS; COKE & COAL; NON-METALLIC	PJ
69	GNGSWKPL		SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; WKPL REQTS	PJ
70	DCACPAP2	Coal:Pulp&Paper	PAP	CAC	SECONDARY REQTS; COKE & COAL; PULP&PAPER; REGION 2	PJ
71	DCACXIN	Coal:Other Ind		CAC	SECONDARY REQTS; COKE & COAL; OTHER IND	PJ
72	DCACSUP	Coal:Mining Own Use	REF	CAC	PRODUCER REQTS; COKE & COAL	PJ
73	DBGSNMT	Biogas:Cement	NMT	BGS	BIOGAS EXTRACTED FROM RICHMOND MUNICIPAL DUMP	PJ
74	DHOGTOTSE	Hog:Secondary Reqts	SUP	HOG	SECONDARY REQTS; HOG FUEL; TOTAL	PJ
75	GHOGTOT	Hog:Converted to Elc				PJ
76	GLIQPAP	Liq:Converted to Elc	PAP	LIQ	USED TO GENERATE ELEC; PULPING LIQOUR;PULP&PAPER	PJ
77	DLIQPAPSE	Liq:Pulp&Paper	PAP	LIQ	SECONDARY REQTS; PULPING LIQUORS; PULP&PAPER	PJ
78	DOTHPAP	Biogas&Tall Oil:P&P	PAP	OTH	SECONDARY REQTS; OTHER FUEL; PULP&PAPER	PJ
79	DELCPAPSE	Elec:Pulp&Paper	PAP	ELC	ELECTRICITY; PULP&PAPER	PJ
80	DELCWOD	Elec:Wood	WOD	ELC	SECONDARY REQTS; ELECTRICITY; WOOD PRODUCTS	PJ
81	DELCPMT	Elec:Primary Metals	PMT	ELC	SECONDARY REQTS; ELECTRICITY; PRIMARY METALS	PJ
82	DELCNMT	Elec:Cement	NMT	ELC	SECONDARY REQTS; ELECTRICITY; NON-METALLIC	PJ
83	DELCCHE	Elec:Chemicals	CHE	ELC	SECONDARY REQTS; ELECTRICITY; CHEMICALS	PJ
84	DELCXMA	Elec:Other Manf	XMA	ELC	SECONDARY REQTS; ELECTRICITY; OTHER MANUFACTURING	PJ
85	DELCMIN		MIN	ELC	SECONDARY REQTS; ELECTRICITY; MINING	PJ
86	DELCSUP	Elec:Losses	SUP	ELC	PRODUCER REQTS; ELECTRICITY	PJ
87	GELCUTL	Elec:From Utl(Thermal)	SUP	ELC	THERMAL GENERATION; ELEC; UTILITIES	PJ
88	GELCIND	Elec:From Ind(Thermal)	IND	ELC	THERMAL GENERATION; ELEC; INDUSTRIAL	PJ
89	PELCCOM	Commercial	COM	ELC	NOMINAL PRICE; ELECTRICITY; COMMERCIAL	$/GJ
90	PELCPAP	Large Industrial	PAP	ELC	NOMINAL PRICE; ELECTRICITY; PULP&PAPER	$/GJ
91	PELCWOD	Small Industrial	WOD	ELC	NOMINAL PRICE; ELECTRICITY; WOOD PRODUCTS	$/GJ
92	PELCRES	Residential	RES	ELC	NOMINAL PRICE; ELECTRICITY; RESIDENTIAL	$/GJ
93	PNGSRES	Residential Retail	RES	NGS	NOMINAL PRICE; NATURAL GAS; RESIDENTIAL (AVE)	$/GJ
94	PNGSCOM	Commercial Retail	COM	NGS	NOMINAL PRICE; NATURAL GAS; COMMERCIAL (AVE)	$/GJ
95	PNGSPAP	Large Industrial Retail	PRI	NGS	NOMINAL PRICE; NATURAL GAS; PULP&PAPER (AVE)	$/GJ
96	PNGSWOD	Small Industrial Retail	PRI	NGS	NOMINAL PRICE; NATURAL GAS; WOOD PRODUCTS	$/GJ
97	PHFOPAP	Heavy Fuel Oil Pulp&Paper	PAP	HFO	NOMINAL PRICE; HEAVY FUEL OIL; PULP&PAPER	$/GJ
98	PMOGROD	Motor Gasoline - Leaded	ROD	MOG	NOMINAL PRICE; MOTOR GASOLINE; ROAD TRANSPORT(VAN)	$/GJ
99	PAVTAIR	Aviation Turbo Fuel	AIR	AVT	NOMINAL PRICE; AVIATION TURBO; AIR	$/GJ
100	PHFOIND	Heavy Fuel Oil, Industrial	PRI	HFO	NOMINAL PRICE, HEAVY FUEL OIL; INDUSTRIAL	$/GJ
101	PLFORES	Light Fuel Oil, Residential	RES	LFO	NOMINAL PRICE; LIGHT FUEL OIL; RESIDENTIAL	$/GJ
102	PLFOCOM	Light Fuel Oil, Commercial	COM	LFO	NOMINAL PRICE; LIGHT FUEL OIL; COMMERCIAL	$/GJ
103	PLPGIND	LPGs Industrial	IND	LPG	NOMINAL PRICE; LPGs; INDUSTRIAL	$/GJ
104	PCPI	Consumer Price Index			CONSUMER PRICE INDEX (1981=1) VANCOUVER	(81=100)

Record#	LAST_ACTUL	Y1988	Y1989	Y1990	Y1991	Y1992
1	1989	43.35300	44.80680	47.06820	47.41400	48.19500
2	1989	11.69400	11.55110	11.41060	10.11070	8.67334
3	1989	1.36500	1.33770	1.31095	0.88473	0.85757
4	1989	71.78000	78.34070	81.35590	84.15170	88.51210
5	1989	1.59900	3.28725	3.41483	3.49962	3.75805
6	1989	0.00600	0.00588	0.00576	0.00565	0.00553
7	1989	29.41500	33.38790	33.37720	32.45320	32.67090
8	1989	1.16900	1.24800	1.27296	1.29842	1.32439
9	1989	13.32000	13.65140	13.76800	14.07540	14.25260
10	1989	15.74000	16.69740	17.11480	17.37150	17.63210
11	1989	12.52200	12.92030	13.06240	13.14370	13.24860
12	1988	0.36128	0.32224	0.32436	0.32860	0.33257
13	1989	39.02200	44.40000	45.50200	46.56900	47.63460
14	1989	125.07200	129.30200	127.16700	126.39100	125.75800
15	1989	5.05200	5.12500	5.22450	5.30960	5.38053
16	1986	0.85900	0.92682	0.99574	1.06400	1.13294
17	1985	0.04129	0.04305	0.03866	0.04386	0.04476
18	1985	0.61427	0.63989	0.66483	0.65362	0.63629
19	1985	0.16776	0.17343	0.17144	0.10786	0.04982
20	1986	20.09430	23.38860	23.56570	18.70800	14.61970
21	1985	0.12743	0.09499	0.09084	0.07130	0.05241
22	1988	-1.53488	0.09589	0.09589	0.09589	0.09589
23	1989	0.25400	0.34212	0.42922	0.52537	0.47883
24	1989	2.89301	3.11588	3.11336	3.29531	3.35717
25	1985	0.05697	0.05056	0.05083	0.05733	0.05779
26	1985	0.03772	0.03703	0.03848	0.03783	0.03683
27	1985	0.23272	0.24058	0.23782	0.16826	0.10650
28	1988	0.46586	0.50275	0.50343	0.52704	0.54044
29	1988	1.20894	1.37000	1.37000	1.37000	1.37000
30	1989	0.00500	0.02081	0.01629	0.01596	0.01628
31	1988	2.00000	1.83971	1.60248	1.19422	0.90686
32	1985	0.10090	0.09526	0.09184	0.10365	0.10499
33	1985	0.09334	0.09288	0.09666	0.09445	0.09347
34	1985	0.71986	0.74417	0.73564	0.70797	0.70557
35	1988	10.35780	7.55390	7.11770	6.82621	6.31284
36	1988	0.30711	0.32647	0.33362	0.34605	0.35283
37	1988	4.35878	12.12810	12.12810	12.12810	12.12810
38	1989	0.16000	0.47440	0.47247	0.47482	0.45169
39	1989	2.52000	2.54662	2.57366	2.60113	2.62903
40	1985	0.75139	0.60082	0.54683	0.42972	0.31762
41	1985	0.01226	0.01220	0.01270	0.01240	0.01228
42	1985	0.26943	0.27853	0.27533	0.26498	0.26408
43	1985	0.36972	0.27719	0.26280	0.25318	0.23624
44	1988	-0.32027	-0.76874	-0.76874	-0.76874	-0.76874
45	1989	0.00700	0.22466	0.16342	0.11039	0.12822
46	1989	17.25100	17.25110	17.28080	16.75280	16.63420
47	1989	0.31800	0.31275	0.31275	0.30929	0.30587
48	1989	1.90200	1.98949	1.86512	1.87365	1.90757
49	1988	4.42100	4.80970	4.80424	4.83744	4.84150
50	1989	3.14000	3.64479	3.36051	4.30480	4.30050
51	1988	0.71000	0.70652	0.73526	0.71842	0.71100
52	1985	16.76250	16.60850	18.16830	18.29630	18.80930
53	1989	0.07500	0.54625	0.16331	0.19789	0.24561
54	1988	7.86500	7.97169	7.96192	8.03616	8.04359
55	1988	2.58000	4.11000	4.92825	5.24966	5.25185
56	1985	13.90640	14.05180	14.00750	14.30490	14.99090
57	1985	4.30762	4.55348	4.54130	4.56547	4.58720
58	1988	12.08380	5.42000	5.50130	5.58382	5.66758
59	1986	23.51890	23.41220	23.68690	31.36300	36.91240
60	1985	2.14000	2.02843	1.81427	2.01416	2.06300
61	1985	2.71820	2.71252	2.83163	2.77615	2.75761
62	1988	18.66200	24.09800	25.13490	25.13490	25.13490
63	1988	1.24537	0.47942	0.73549	0.81672	0.78710
64	1985	6.87541	5.41252	6.04948	6.44639	6.77803

65	1989	3.27739	3.62456	3.67923	3.92464	4.17504
66	1990	0.89900	44.03900	13.37800	31.79030	35.82150
67	1989	14.68600	17.47630	18.09250	20.48800	21.86010
68	1985	0.94508	0.94249	0.98317	0.96316	0.95592
69	0	0.00000	0.00000	0.00000	0.00000	1.30717
70	1988	0.24612	0.09376	0.25549	0.25529	0.25629
71	1988	2.53534	2.53578	2.53578	2.53578	2.53578
72	1989	4.01300	5.11088	5.21423	5.27590	5.34451
73	1988	0.15696	0.15653	0.16329	0.15996	0.15876
74	1986	67.73400	68.71170	68.78110	70.39390	72.32080
75	0	2.98095	3.31164	3.34326	3.47968	5.26715
76	1986	5.48015	6.11650	6.15418	6.31664	6.37775
77	1986	131.18500	132.42100	133.00500	135.61000	137.29000
78	0	0.75000	0.70965	0.72323	0.86752	0.93078
79	1988	37.95790	40.57860	41.72410	44.11050	45.51510
80	1985	11.27000	10.92240	10.93090	11.08180	11.32500
81	1985	0.69000	0.59217	0.55115	0.70853	0.72021
82	1985	0.66400	0.57091	0.59691	0.57989	0.57515
83	1985	4.00000	4.64424	4.79364	4.92407	5.01650
84	1985	6.74653	6.69014	7.06098	7.00663	7.22288
85	1985	10.47270	11.10120	10.98510	10.69490	10.76400
86	1989	17.51900	18.19300	19.01330	19.39330	19.63350
87	1990	0.30000	15.10000	4.60000	11.18380	13.61140
88	1988	9.65455	9.83669	9.87856	10.41340	11.98360
89	1988	14.26500	14.33630	14.85240	15.06040	15.46700
90	1988	8.80400	8.84802	9.16655	9.29488	9.54584
91	1988	12.51800	12.58060	13.03350	13.21600	13.57280
92	1988	15.39900	15.47600	16.03310	17.39560	17.86530
93	1990	4.65280	4.66387	4.66387	5.21769	5.54109
94	1990	4.49434	4.49434	4.49434	4.71248	5.01503
95	1990	2.08396	2.08396	2.08396	2.18125	2.39690
96	1990	3.50945	3.50945	3.50945	3.65985	3.93943
97	1988	2.26960	3.38852	3.63100	3.90659	4.27384
98	1989	13.87998	15.21581	17.78400	18.72690	19.66330
99	1989	8.34094	8.64487	11.69400	12.05550	12.61670
100	1989	2.33070	2.82171	4.00631	4.31039	4.71559
101	1989	7.97130	7.62565	9.39359	10.55390	11.08380
102	1989	6.26758	6.22932	7.45320	7.82877	8.26713
103	1985	5.11185	5.69838	6.01651	6.32672	6.68202
104	1988	1.38100	1.44315	1.52252	1.61387	1.68972

Record#	Y1993	Y1994	Y1995	Y1996	Y1997	Y1998	Y1999
1	49.34750	50.36710	51.85780	52.69440	53.80380	54.83800	56.22530
2	7.03905	5.60079	4.63623	4.50323	4.37325	4.24618	4.12176
3	0.83111	0.80518	0.77984	0.75512	0.73102	0.70754	0.68461
4	92.86470	95.91540	97.36610	99.38360	101.41300	104.20100	106.09600
5	3.77263	3.80947	3.83858	3.85630	3.87043	3.87513	3.87182
6	0.00542	0.00532	0.00521	0.00511	0.00500	0.00490	0.00480
7	33.42470	34.49490	35.94430	36.94760	38.04590	38.99790	39.73800
8	1.35088	1.37789	1.40545	1.43356	1.46223	1.49148	1.52131
9	14.91420	15.18870	15.34580	15.51880	15.69990	15.82370	15.94890
10	17.89660	18.16500	18.43750	18.71410	18.99480	19.27970	19.56890
11	13.35090	13.43960	13.50470	13.55250	13.59460	13.60670	13.60050
12	0.33709	0.34184	0.34668	0.35145	0.35607	0.36060	0.36489
13	48.69950	49.76220	50.83400	51.89610	52.94860	53.98970	55.01130
14	126.15600	126.73700	127.42200	127.39100	128.31800	129.15000	130.05400
15	5.45226	5.52478	5.60459	5.68348	5.76145	5.83529	5.90507
16	1.20260	1.23724	1.27153	1.30506	1.33789	1.37002	1.40130
17	0.04470	0.04238	0.03987	0.03820	0.03645	0.03448	0.03235
18	0.60271	0.59257	0.58028	0.56662	0.55159	0.53629	0.52054
19	0.01297	0.00175	0.01136	0.02549	0.04362	0.05690	0.06326
20	15.96500	16.32680	16.81460	17.26730	17.36990	17.44650	17.50180
21	0.04173	0.03869	0.03742	0.03664	0.03550	0.03284	0.03564
22	0.09589	0.09589	0.09589	0.09589	0.09589	0.09589	0.09589
23	0.41322	0.44288	0.45083	0.43417	0.42371	0.42558	0.42111
24	3.56944	3.65390	3.74586	3.83047	3.86748	3.89938	3.92723
25	0.05678	0.05491	0.05147	0.04917	0.04687	0.04447	0.04169
26	0.03488	0.03430	0.03358	0.03279	0.03193	0.03104	0.03013
27	0.06934	0.06012	0.07402	0.09361	0.11877	0.13719	0.14602
28	0.56269	0.57929	0.59008	0.59988	0.60249	0.60489	0.60720
29	1.37000	1.37000	1.37000	1.37000	1.37000	1.37000	1.37000
30	0.01621	0.01558	0.01557	0.01549	0.01530	0.01505	0.01491
31	0.74001	0.67141	0.64665	0.63806	0.61929	0.57050	0.61940
32	0.10381	0.09966	0.09352	0.08944	0.08530	0.08084	0.07580
33	0.09505	0.09592	0.09911	0.10093	0.10151	0.10161	0.10164
34	0.73107	0.76633	0.81498	0.87559	0.95342	1.01039	1.03769
35	5.74837	6.26552	6.39879	5.98959	5.70353	5.79209	5.74327
36	0.36222	0.37213	0.37759	0.38238	0.38241	0.38223	0.38191
37	12.12810	12.12810	12.12810	12.12810	12.12810	12.12810	12.12810
38	0.43714	0.44120	0.43841	0.43030	0.42523	0.42164	0.41663
39	2.65738	2.68618	2.71544	2.74517	2.77536	2.80604	2.83721
40	0.25472	0.23419	0.22679	0.22235	0.21554	0.19911	0.21621
41	0.01248	0.01260	0.01302	0.01326	0.01333	0.01335	0.01335
42	0.27362	0.28682	0.30503	0.32772	0.35685	0.37817	0.38839
43	0.21761	0.23468	0.23907	0.22557	0.21613	0.21905	0.21744
44	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874
45	0.14694	0.13246	0.12648	0.13010	0.13050	0.12629	0.12471
46	16.28980	16.09140	15.83820	15.51370	15.16690	14.76930	14.32710
47	0.30249	0.29914	0.29584	0.29256	0.28933	0.28613	0.28296
48	1.90896	1.88883	1.89475	1.90003	1.89814	1.89544	1.89709
49	4.85994	4.87476	4.88661	4.88257	4.89409	4.90043	4.90375
50	4.30050	4.30050	4.30480	4.30480	4.30480	4.30480	4.30480
51	0.72302	0.72966	0.75390	0.76771	0.77216	0.77294	0.77312
52	19.31900	19.82800	20.29580	20.90110	21.88480	22.79160	23.34820
53	0.28827	0.22377	0.23888	0.24913	0.25001	0.24045	0.24462
54	8.08069	8.10905	8.13029	8.11749	8.13743	8.14589	8.14740
55	5.26882	5.28202	5.29345	5.28830	5.29792	5.30244	5.30391
56	15.45890	15.69020	15.67180	15.76880	15.88590	15.86990	15.59800
57	4.63201	4.65270	4.62826	4.63985	4.65965	4.63371	4.61169
58	5.75259	5.83888	5.92646	6.01536	6.10559	6.19717	6.29013
59	38.56680	40.04920	40.78620	41.53260	41.91710	42.30340	42.69870
60	2.09188	2.08553	2.06503	2.08134	2.09316	2.10363	2.11898
61	2.81540	2.85339	2.96167	3.03060	3.06396	3.08382	3.10241
62	25.13490	25.13490	25.13490	25.13490	25.13490	25.13490	25.13490
63	0.73814	0.68999	0.64415	0.60251	0.57268	0.54772	0.54256
64	7.08655	7.07325	7.13749	7.33563	7.47249	7.47599	7.50829

65	4.35810	4.59151	4.78430	4.94485	5.05252	5.16467	5.28196
66	36.31390	39.31500	38.49730	41.85880	42.37430	41.28910	40.44800
67	23.60120	24.37610	24.68690	25.41790	25.95290	26.46610	26.83290
68	0.97507	0.98727	1.02367	1.04635	1.05664	1.06219	1.06721
69	6.53143	6.62256	6.62256	6.62256	6.62256	6.62256	6.62256
70	0.25393	0.25802	0.25621	0.25383	0.25137	0.24873	0.24600
71	2.53578	2.53578	2.53578	2.53578	2.53578	2.53578	2.53578
72	5.43881	5.53837	5.63371	5.72148	5.80420	5.88187	5.95427
73	0.16194	0.16397	0.17001	0.17378	0.17549	0.17641	0.17724
74	75.51590	77.69450	79.22630	79.70050	80.32610	80.69980	81.01000
75	7.56182	11.31800	13.65580	13.66700	13.68640	13.70570	13.72550
76	6.54577	6.64434	6.66950	6.68223	6.69249	6.69860	6.70213
77	139.80200	142.13500	142.27200	142.14100	141.99100	141.78700	141.61600
78	1.06106	1.07738	1.11238	1.14608	1.16627	1.18735	1.21002
79	51.14350	53.11920	55.21920	57.20670	58.57100	60.23660	62.09930
80	11.58690	11.77670	11.83810	11.99760	12.16550	12.19990	12.22980
81	0.72515	0.72812	0.73754	0.74031	0.74317	0.74588	0.74818
82	0.58797	0.59830	0.63362	0.65117	0.65997	0.66870	0.67658
83	5.19425	5.37923	5.50292	5.62194	5.74178	5.86805	5.99501
84	7.50672	7.96453	8.48336	9.10627	9.90040	10.73440	11.42380
85	12.37010	12.64070	12.95920	11.19190	11.49230	10.94910	11.25040
86	20.42730	21.00200	21.53920	22.18660	22.61050	23.28040	23.88070
87	18.81050	24.63340	25.93350	27.09910	27.27890	26.92790	26.65800
88	13.73670	15.46700	17.16080	17.53370	17.70530	17.87380	18.04170
89	15.93100	16.40890	16.90120	17.40820	17.93050	18.46840	19.02250
90	9.83222	10.12720	10.43100	10.74390	11.06620	11.39820	11.74020
91	13.98000	14.39940	14.83140	15.27630	15.73460	16.20660	16.69280
92	18.40130	18.95330	19.52190	20.10760	20.71080	21.33210	21.97210
93	5.90633	6.31558	6.76779	7.24114	7.73480	8.23239	8.73885
94	5.35562	5.73660	6.15726	6.60885	7.08227	7.53301	7.99148
95	2.64841	2.93380	3.25593	3.60029	3.92428	4.23131	4.54374
96	4.25730	4.61452	5.01218	5.40428	5.81644	6.20850	6.60738
97	4.63707	5.06621	5.56184	6.08730	6.67257	7.34724	8.10076
98	20.58060	21.53490	22.65470	23.79970	24.89190	26.38060	27.83970
99	13.23890	13.85100	14.72830	15.54600	16.25020	17.60260	18.61520
100	5.11637	5.58987	6.13672	6.71649	7.36225	8.10667	8.93807
101	11.60700	12.14360	12.81370	13.49760	14.12580	15.07570	15.98790
102	8.70151	9.17647	9.75272	10.35180	10.95130	11.76510	12.59780
103	7.03319	7.41992	7.87933	8.35772	8.84377	9.47959	10.13710
104	1.76238	1.83816	1.91353	1.99007	2.06768	2.14625	2.22566

Record#	Y2000	Y2001	Y2002	Y2003	Y2004	Y2005	Y2006
1	57.76600	59.29420	60.70360	61.95020	63.04900	63.97590	64.81790
2	3.99987	3.88035	3.76322	3.64844	3.53586	3.42540	3.31698
3	0.66223	0.64036	0.61899	0.59813	0.57773	0.55780	0.53831
4	108.51000	111.31800	113.57700	115.45700	117.40100	119.34300	121.13500
5	3.86190	3.84827	3.83259	3.82274	3.82342	3.83746	3.86233
6	0.00471	0.00461	0.00452	0.00443	0.00434	0.00426	0.00417
7	40.67870	41.62060	42.46580	43.38700	44.33640	45.38440	46.60330
8	1.55173	1.59053	1.63029	1.67105	1.71282	1.75564	1.79953
9	16.06830	16.40100	16.73660	17.07690	17.41840	17.76520	17.85520
10	19.86240	20.16040	20.46280	20.76970	21.08130	21.39750	21.71850
11	13.57520	13.55820	13.55740	13.57740	13.63300	13.71210	13.80390
12	0.36914	0.37345	0.37772	0.38205	0.38630	0.39051	0.39473
13	56.02360	57.00260	57.94600	58.85470	59.72720	60.56330	61.36490
14	130.96900	131.83400	132.62900	133.36200	134.09800	134.74500	135.31600
15	5.97243	6.04056	6.10628	6.17278	6.23535	6.29559	6.35509
16	1.43203	1.46212	1.49151	1.52020	1.54816	1.57537	1.60187
17	0.02989	0.02709	0.02405	0.02080	0.01733	0.01359	0.00961
18	0.50514	0.49050	0.47699	0.46552	0.45676	0.45068	0.44658
19	0.07236	0.07892	0.08389	0.08774	0.09125	0.09509	0.10034
20	17.52820	17.65630	17.75200	17.92140	18.20660	18.61820	18.82950
21	0.03567	0.03397	0.03165	0.02920	0.02680	0.02469	0.02279
22	0.09589	0.09589	0.09589	0.09589	0.09589	0.09589	0.09589
23	0.41381	0.40897	0.40564	0.40125	0.39718	0.39366	0.39023
24	3.95093	3.98768	4.03057	4.07771	4.13354	4.19993	4.23183
25	0.03850	0.03490	0.03100	0.02680	0.02232	0.01751	0.01238
26	0.02924	0.02839	0.02761	0.02694	0.02644	0.02608	0.02585
27	0.15863	0.16773	0.17464	0.17997	0.18485	0.19016	0.19745
28	0.60936	0.61218	0.61518	0.61905	0.62433	0.63117	0.63730
29	1.37000	1.37000	1.37000	1.37000	1.37000	1.37000	1.37000
30	0.01475	0.01457	0.01440	0.01426	0.01413	0.01400	0.01387
31	0.62073	0.59104	0.55034	0.50788	0.46628	0.42941	0.39636
32	0.07002	0.06346	0.05636	0.04873	0.04059	0.03185	0.02250
33	0.10267	0.10354	0.10433	0.10480	0.10539	0.10602	0.10674
34	1.07673	1.10487	1.12622	1.14271	1.15780	1.17424	1.19678
35	5.68157	5.79254	5.37330	5.36431	5.34642	5.02396	5.01370
36	0.38136	0.38102	0.38032	0.38062	0.38239	0.38572	0.38926
37	12.12810	12.12810	12.12810	12.12810	12.12810	12.12810	12.12810
38	0.41119	0.40664	0.40240	0.39817	0.39443	0.39088	0.38734
39	2.86887	2.90103	2.93370	2.96690	3.00062	3.03488	3.06968
40	0.21642	0.20609	0.19199	0.17716	0.16262	0.14977	0.13825
41	0.01349	0.01360	0.01370	0.01377	0.01384	0.01393	0.01402
42	0.40300	0.41353	0.42152	0.42769	0.43334	0.43950	0.44793
43	0.21541	0.21907	0.20523	0.20494	0.20435	0.19371	0.19337
44	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874	-0.76874
45	0.12419	0.12278	0.12100	0.11985	0.11889	0.11776	0.11663
46	13.86050	13.38830	12.92010	12.49530	12.13430	11.84630	11.63250
47	0.27983	0.27674	0.27368	0.27065	0.26766	0.26470	0.26177
48	1.89767	1.89708	1.89682	1.89717	1.89719	1.89706	1.89706
49	4.90214	4.90703	4.91634	4.92859	4.95320	4.97762	4.99962
50	4.30480	4.30480	4.30480	4.30480	4.30480	4.30480	4.30480
51	0.78096	0.78756	0.79361	0.79719	0.80167	0.80649	0.81190
52	24.44900	25.50170	26.52110	27.52790	28.46320	29.37030	30.36590
53	0.24605	0.24529	0.24410	0.24502	0.24511	0.24488	0.24478
54	8.13772	8.14318	8.15906	8.18197	8.23322	8.28447	8.33061
55	5.30046	5.30363	5.31132	5.32207	5.34525	5.36838	5.38920
56	15.37720	15.18710	15.11860	15.10330	15.13790	15.22400	15.21110
57	4.59051	4.57026	4.55432	4.54217	4.53421	4.53131	4.52838
58	6.38448	6.48025	6.57745	6.67612	6.77626	6.87790	6.98107
59	43.10430	43.47100	43.86850	44.27810	44.70640	45.15870	45.56320
60	2.14258	2.16182	2.18487	2.21443	2.25466	2.30691	2.33441
61	3.15294	3.19995	3.24622	3.28385	3.32663	3.37237	3.42124
62	25.13490	25.13490	25.13490	25.13490	25.13490	25.13490	25.13490
63	0.53952	0.53901	0.54018	0.54377	0.54992	0.55783	0.52844
64	7.53746	7.50032	7.62523	7.63194	7.66136	7.82489	7.92539

65	5.40481	5.50897	5.62017	5.73494	5.85429	5.97881	6.14191
66	40.25800	40.25800	40.25800	40.25800	40.25800	40.25800	40.25800
67	27.35830	27.87940	28.31970	28.78870	29.25000	29.75980	30.16220
68	1.08313	1.09773	1.11196	1.12313	1.13594	1.14965	1.16438
69	6.62256	6.62256	6.62256	6.62256	6.62256	6.62256	6.62256
70	0.24318	0.24046	0.23819	0.23617	0.23457	0.23344	0.23373
71	2.53578	2.53578	2.53578	2.53578	2.53578	2.53578	2.53578
72	6.02521	6.09614	6.16707	6.23800	6.30872	6.37923	6.44974
73	0.17989	0.18231	0.18468	0.18653	0.18866	0.19094	0.19338
74	81.28290	81.78490	81.88320	81.98800	82.14120	82.35820	82.66140
75	13.74590	13.77460	13.71970	13.66730	13.61860	13.57420	13.59060
76	6.70316	6.73034	6.73320	6.74115	6.75891	6.78823	6.80492
77	141.46400	141.73500	141.57500	141.48000	141.50600	141.67900	141.92500
78	1.23437	1.27244	1.31222	1.35389	1.39841	1.44624	1.46609
79	64.00160	66.41100	68.61660	70.89590	73.24310	75.65340	76.61140
80	12.25390	12.24670	12.23870	12.22440	12.20700	12.18950	12.18190
81	0.75001	0.75132	0.75274	0.75411	0.75483	0.75582	0.75385
82	0.69133	0.70128	0.71039	0.71672	0.72329	0.72960	0.74093
83	6.10676	6.18811	6.25685	6.31561	6.34867	6.37688	6.39318
84	12.39600	13.32670	14.20920	15.04060	15.73740	16.35380	16.98150
85	11.55160	10.55180	10.81150	11.05050	11.26840	11.46510	11.64560
86	24.65940	25.47900	26.09250	26.83870	27.53470	28.19120	28.67060
87	26.60430	26.61370	26.62320	26.63290	26.64280	26.65280	26.66300
88	18.20920	18.36040	18.52890	18.70760	18.90420	19.12230	19.33630
89	19.70730	20.39710	21.11100	21.84980	22.61450	23.40610	24.22530
90	12.16290	12.58850	13.02920	13.48520	13.95710	14.44560	14.95120
91	17.29380	17.89910	18.52560	19.17400	19.84500	20.53960	21.25850
92	22.76310	23.55980	24.38440	25.23790	26.12110	27.03540	27.98170
93	9.28509	9.79361	10.27430	10.73560	11.11140	11.50030	11.90280
94	8.48550	8.94578	9.38117	9.79953	10.14250	10.49750	10.86490
95	4.88404	5.19741	5.48936	5.76635	5.96816	6.17705	6.39325
96	7.03855	7.43903	7.81628	8.17753	8.46372	8.75996	9.06656
97	8.97098	9.79571	10.58680	11.35190	11.94200	12.51670	13.11410
98	29.45710	31.00470	32.54470	34.06020	35.34310	36.65300	37.97140
99	19.89570	21.10960	22.33170	23.49940	24.43580	25.40940	26.33340
100	9.89824	10.80820	11.68110	12.52530	13.17630	13.81050	14.46970
101	17.01700	17.99110	18.95470	19.89210	20.64600	21.41530	22.17960
102	13.54960	14.45050	15.32980	16.18270	16.85340	17.52530	18.20500
103	10.88560	11.59630	12.29050	12.96590	13.50460	14.04390	14.59210
104	2.30579	2.38649	2.47002	2.55647	2.64594	2.73855	2.83440

Record#	Y2007	Y2008	Y2009	Y2010
1	65.61770	66.41450	67.30930	68.29650
2	3.21064	3.10632	3.00397	2.90353
3	0.51926	0.50064	0.48244	0.46465
4	123.03900	125.00100	127.08300	129.25300
5	3.89574	3.93507	3.97485	4.01434
6	0.00409	0.00401	0.00393	0.00385
7	47.96290	49.33730	50.78890	52.30220
8	1.84452	1.89064	1.93790	1.98635
9	17.94480	18.03320	18.12200	18.21110
10	22.04420	22.37490	22.71050	23.05120
11	13.89620	13.98420	14.06890	14.15230
12	0.39885	0.40299	0.40703	0.41109
13	62.13470	62.87200	63.57970	64.25930
14	135.79300	136.16300	136.46000	136.69100
15	6.41077	6.46574	6.51696	6.56752
16	1.62772	1.65290	1.67747	1.70147
17	0.00558	0.00146	-0.00280	-0.00720
18	0.44394	0.44237	0.44097	0.43958
19	0.10608	0.11186	0.11768	0.12338
20	19.11780	19.39240	19.67770	19.97130
21	0.02129	0.01995	0.01848	0.01679
22	0.09589	0.09589	0.09589	0.09589
23	0.38662	0.38306	0.37960	0.37616
24	4.26879	4.31360	4.35911	4.40511
25	0.00719	0.00188	-0.00361	-0.00927
26	0.02569	0.02560	0.02552	0.02544
27	0.20541	0.21344	0.22150	0.22941
28	0.64437	0.65181	0.65948	0.66735
29	1.37000	1.37000	1.37000	1.37000
30	0.01375	0.01362	0.01350	0.01338
31	0.37035	0.34698	0.32148	0.29197
32	0.01308	0.00341	-0.00656	-0.01687
33	0.10753	0.10837	0.10920	0.11004
34	1.22142	1.24624	1.27119	1.29565
35	5.01016	5.01950	5.02788	5.03051
36	0.39375	0.39801	0.40245	0.40704
37	12.12810	12.12810	12.12810	12.12810
38	0.38381	0.38031	0.37686	0.37343
39	3.10504	3.14096	3.17745	3.21452
40	0.12917	0.12102	0.11213	0.10184
41	0.01412	0.01423	0.01434	0.01445
42	0.45716	0.46644	0.47578	0.48494
43	0.19325	0.19356	0.19384	0.19392
44	-0.76874	-0.76874	-0.76874	-0.76874
45	0.11560	0.11457	0.11351	0.11247
46	11.45900	11.31100	11.16350	11.01420
47	0.25888	0.25601	0.25318	0.25038
48	1.89712	1.89711	1.89709	1.89709
49	5.01897	5.03541	5.04969	5.06198
50	4.30480	4.30480	4.30480	4.30480
51	0.81795	0.82429	0.83065	0.83702
52	31.40800	32.51100	33.66440	34.85090
53	0.24495	0.24493	0.24488	0.24488
54	8.37110	8.40535	8.43501	8.46040
55	5.40749	5.42298	5.43640	5.44792
56	15.21650	15.22090	15.22650	15.23460
57	4.52548	4.52270	4.51989	4.51711
58	7.08579	7.19207	7.29995	7.40945
59	45.98120	46.42550	46.87580	47.33160
60	2.37233	2.41430	2.45808	2.50364
61	3.47350	3.52772	3.58279	3.63866
62	25.13490	25.13490	25.13490	25.13490
63	0.50162	0.47842	0.45699	0.43598
64	8.05341	8.19518	8.33866	8.48297

65	6.31064	6.48867	6.67225	6.86152
66	40.25800	40.25800	40.25800	40.25800
67	30.64140	31.16690	31.71250	32.24700
68	1.18021	1.19666	1.21334	1.23023
69	6.62256	6.62256	6.62256	6.62256
70	0.23418	0.23500	0.23584	0.23670
71	2.53578	2.53578	2.53578	2.53578
72	6.52004	6.59035	6.66065	6.73074
73	0.19601	0.19874	0.20151	0.20432
74	82.99050	83.43250	83.88090	84.33480
75	13.60900	13.63170	13.65490	13.67880
76	6.82714	6.85918	6.89210	6.92572
77	142.22600	142.77600	143.33600	143.90700
78	1.48775	1.51053	1.53366	1.55714
79	77.58610	78.59790	79.63740	80.70320
80	12.17440	12.16730	12.16000	12.15290
81	0.75235	0.75122	0.75097	0.75075
82	0.75243	0.76410	0.77595	0.78798
83	6.40953	6.42619	6.44261	6.45882
84	17.61040	18.26570	18.94310	19.64100
85	11.81480	11.97580	12.13920	10.20870
86	29.13930	29.60780	30.09630	30.60770
87	26.67330	26.68380	26.69460	26.70540
88	19.56270	19.80960	20.06170	20.31900
89	25.07310	25.95070	26.85900	27.79910
90	15.47450	16.01610	16.57670	17.15690
91	22.00250	22.77260	23.56960	24.39460
92	28.96100	29.97460	31.02380	32.10960
93	12.31930	12.75050	13.19680	13.65870
94	11.24520	11.63870	12.04610	12.46770
95	6.61700	6.84860	7.08831	7.33640
96	9.38388	9.71233	10.05230	10.40410
97	13.73890	14.39380	15.07660	15.78870
98	39.38010	40.93250	42.54750	44.22780
99	27.38480	28.58110	29.76170	30.99230
100	15.15900	15.88160	16.63500	17.42060
101	23.00700	23.94170	24.91530	25.92950
102	18.93200	19.73200	20.56650	21.43700
103	15.17580	15.81210	16.47570	17.16770
104	2.93360	3.03628	3.14255	3.25254

APPENDIX D

SENSITIVITY TEST FOR

ELECTRICITY EMISSION FACTORS

Appendix D

Sensitivity Test for Electricity Emission Factors

Section 7 of the main report discusses different approaches to meeting increased demand for electricity. Two strategies were compared: a CO-intensive response and a hydro-intensive response. In this appendix, we provide results of a sensitivity test in which the emission factor for electricity is based on a CO_2-intensive supply response. Specifically, an emission factor of 60.07 t/TJ is used instead of 12.32 t/TJ. The higher factor corresponds to the mix of resources that would be used under a CO_2-intensive strategy to meet a 10% increase in demand by 1997/8.

The results in Exhibit E.1 can be compared to those in Exhibit 6.1. The main findings are:

- conversions to electricity from LFO and natural gas still generate CO_2 abatement, although their impact is considerably less;
- conversions to electricity become even more expensive per tonne abated;
- measures that conserve electricity generate more significant CO_2 reductions, on the premise that increases to electricity supply (i.e., reductions in demand) will be added to the marginal supply sources -- that is, available energy will be exported to the United States or used to reduce purchases from Alberta.

The change in emission factor would not affect the list of promising measures bounded by the thick black line in Exhibit 9.1, except to add energy-efficient new housing (MUD) as a measure with moderate abatement (instead of low) potential and cost savings. Some measures outside the most promising would be rearranged (e.g., conversion to electricity would shift from high abatement potential (natural gas) and moderate abatement potential (LFO) to low abatement potential).

Exhibit D.1: Abatement Potential and Cost-Effectiveness for Management Measures in the Residential Sector Assuming A CO_2-Intensive Electricity Supply Response

	Annual CO_2 Reductions		Lifetime CO_2 Reductions	Cost-Effectiveness
	kt	% provincial total	(kt)	($/t)
1. User education/practices	700	.08	35,045	-27
2. Air conditioning	<1	0.1	15	3,272
3. High efficiency lighting	110	0.1	2,180	-110
4. Appliances and fixtures	35	<0.1	715	-91
Single Family Dwellings				
a) Space Heating				
5. Energy-efficient new housing	970-1,660	1.1 to 1.8	48,485-83,115	2 to 8
6. Building envelope/ventilation retrofit	690-1,245	0.7 to 1.3	20,780-37,405	7 to 40
7. Heat pump	140	0.1	7,000	-29
8. Passive use of solar				
a) LFO & natural gas	950	1.0	47,415	-9
b) electricity	160	0.1	8,600	-41
9. High efficiency furnace	340	0.4	10,150	5
10. Improved burner efficiency	475	0.5	14,255	11
11. Convert heat source				
11.1 LFO to electricity	130	0.1	6,390	59
11.2 Natural gas to electricity	65	<0.1	3,265	931
b) Water Heating				
12. Tank/line insulation	310	0.3	15,460	-19
13. Improved burner efficiency	175	0.2	3,545	53
14. Heat pump water heaters	110	0.1	2,165	-45
15. Direct use of solar				
a) LFO & natural gas	665	0.7	13,355	107
b) electricity	155	0.2	3,090	31
16. Convert heat source				
16.1 LFO to electric	80	<0.1	1,585	82
16.2 Natural gas to electric	140	0.1	2,850	367

Exhibit D.1: Abatement Potential and Cost-Effectiveness for Management Measures in the Residential Sector Assuming A CO_2-Intensive Electricity Supply Response (cont'd)

	Annual CO_2 Reductions		Lifetime CO_2 F ductions	Cost-Effectiveness
	kt	% provincial total	(kt)	($/t)
Multi Unit Dwellings				
17. Phase leading, load control & power	<5	-	75	-66
a) Space Heating				
18. Energy-efficient new buildings	370-525	0.4 to 0.6	18,385-26,265	-14 to -17
19. Building envelope/ventilation retrofit	170-235	0.2	7,050	-2 to -8
20. Plant efficiency/cogeneration	110	0.1	30	-41
21. Passive use of solar				
a) LFO & natural gas	390	0.4	19,560	-12
b) electricity	135	0.1	6,705	-47
22. High efficiency furnace	290	0.3	11,650	-25
23. Convert heat source				
23.1 LFO to electricity	65	<0.1	3,255	56
23.2 Natural gas to electricity	20	<0.1	965	900
b) Water Heating				
24. Tank insulation/burner efficiency	70	<0.1	2,100	-23
25. Heat pump water heater	25	<0.1	790	-61
26. Direct use of solar				
a) LFO & natural gas	170	0.2	5,070	-7
b) electricity	85	<0.1	2,570	-70
27. Convert heat source				
27.1 LFO to electricity	40	<0.1	805	78
27.2 Natural gas to electricity	50	<0.1	1,005	345

APPENDIX E

POLICY TOOLS FOR SPECIFIC CO_2 MANAGEMENT MEASURES

Appendix E

Policy Tools for Specific CO_2 Management Measures

Forests and Forest Management

(i) Utilization of Harvest Residues and Wood Waste

RD&D:	Environmental research re: appropriate levels of residue removal; market and technical feasibility studies for new products
Financial Incentives:	Tax incentives for capital equipment investments for alternative products, or for increasing use of wood waste
Taxes and Fees:	Carbon tax on or wood waste incineration in combination with policies to encourage wood waste utilization
Marketable Permits:	Permits for wood waste incineration is combination with policies to encourage wood waste utilization
Direct Govt Action:	Investigation of product and market opportunities.

(ii) Plant NSR and Marginal Agricultural Land

RD&D:	Environmental research on: • net increment to CO_2 absorption on a variety of NSR and agricultural lands (including growth potential, soil fertility, existing land cover, etc.); • amount of land available and suitable for replanting.
Information:	Information to community groups and local government to encourage local planting programs; information to farmers to encourage participation in agro-forestry programs
Financial Incentives:	Offsets of other sources (under regulatory CO_2 policy or permits system) for contributions for planting programs; environmental tax credit for contributions; subsidies or caretaker payments to farmers; development of a forestry fund to help finance planting; assistance to community or local planting projects
Marketable Permits:	Allocation of permits based on forest planting contribution

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Direct Govt Action:	Increase funding for re/afforestation programs; development of agro-forestry programs

(iii) Site Treatment

RD&D:	Further research on the implications of various site treatment methods to support government planning (see below)
Taxes and Fees:	Carbon emissions tax for site preparation
Marketable Permits:	Permits required for slash burning emissions (and emissions for other methods of site treatment)
Direct Govt Action:	Incorporation of CO_2 emissions as a criterion in planning method of site treatment

Pulp and Paper Sector

(i) General Efficiency Measures

RD&D:	Enhance development and demonstration activities for energy saving technologies and practices
Information:	Labelling of energy-efficient equipment, (subsidized) mill energy audits; general information transfer to decision-makers through industry associations, trade journals, trade shows, etc.; CIPEC extensions
Regulation:	Limits on carbon dioxide emissions; energy efficiency standards
Financial Incentives:	Tax breaks or low interest loans for energy conservation investments.
Taxes and Fees:	Energy or carbon tax (care must be taken to treat wood wastes appropriately)
Marketable Permits:	Permits are suitable except some care must be taken to exclude emissions from wood waste used to replace fossil fuel from the permit system; otherwise, it would be in the interests of mills to substitute away from wood waste *towards* fossil fuels.

(ii) Process Changes

RD&D:	Research to determine environmental trade-offs between recycle, kraft, and TMP/CTMP; market research; raw material research
Regulation:	see Section 10.2.1; also, legislation specifying percent recycle
Financial Incentives:	Tax breaks, low interest loans, or some form of environmental credit to underwrite capital expenditures
Taxes and Fees:	see Section 10.2.1; also, purchase tax on virgin pulp
Marketable Permits:	see Section 10.2.1

(iii) Substitution to Natural Gas

Regulation:	see Section 10.2.1
Financial Incentives:	Tax incentives, low cost loans, direct payments for conversion costs
Taxes and Fees:	Carbon tax only is appropriate because the incentive must distinguish between fuels of different carbon contents.
Marketable Permits:	see Section 10.2.1

(iv) Substitution to Self-Generated Fuels

RD&D:	Research solutions for burning "difficult" waste woods
Regulation:	see Section 10.2.1
Financial Incentives:	see Section 10.2.1
Taxes and Fees:	see Section 10.2.1; both carbon and general energy tax are valid
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	

Transportation Measures

(i) Vehicle Fuel Efficiency

RD&D:	Support ongoing research.
Information:	Labelling and rating of new and in-use vehicles according to fuel economy
Regulation:	Regulated fuel efficiency standards for new vehicles
Financial Incentives:	Tax or cash rebates for purchases of high efficiency vehicles Tax or cash rebates for low efficiency vehicle trade-ins
Taxes and Fees:	see Section 10.2.1; also purchase taxes for high fuel use cars
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	Explicit goals for new car purchases and vehicle maintenance; performance factor in selecting fleet vehicles

(ii) Driver Training

Information:	Public education through courses (centralized or at-site) or broad-based advertising. Course could be mandatory at the time of vehicle registration/insurance renewal or driver licensing.
Financial Incentives:	Environmental tax credit for completion of a course.
Direct Govt Action:	Develop training program; could include seminars at secondary schools

(iii) Route and Traffic Planning

RD&D:	Monitoring of effectiveness of similar measures in other jurisdictions.
Information:	Information campaign for fleet managers
Regulation:	Restricted hours of operation in the city core; restricted routing; high occupancy vehicle lanes
Taxes and Fees:	see Section 10.2.1

Marketable Permits:	see Section 10.2.1; also, permits for hours of operation or routing
Direct Govt Action:	Investments in traffic planning and management systems.

(iv) Vehicle Maintenance

Regulation:	Mandatory vehicle inspection and maintenance program
Taxes and Fees:	see Section 10.2.1
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	Set up centralized inspection stations; train inspection officers; monitor for quality assurance

(v) Conversion to Natural Gas or Propane

RD&D:	Research to eliminate safety concerns, emissions of formaldehyde; further research on impacts on other GHG; research critical factors affecting CO_2 emissions from alternative fuels
Information:	Advertising campaign to encourage private vehicle owners to convert; readily available and objective information on conversions and environmental impacts.
Regulation:	Develop standards for equipment and for certifying mechanics/garages to undertake conversions.
Financial Incentives:	Incentives for conversion equipment, costs of conversion, and refuelling equipment (station and home compressors)
Taxes and Fees:	see Section 10.2.1
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	Convert fleet vehicles

(vi) Public Transportation

Information:	Continued public education campaign relating transit use to environmental stewardship
Financial Incentives:	Employer-subsidized transit passes

Taxes and Fees:	Variety of taxes and charges to increase the cost of downtown automobile travel, including road fees, parking charges, etc.
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	Investments in expansion of transit service, including more frequent service, quality of service, alternative levels of service

(vii) Land Use Planning

Regulation:	Development regulations and building codes to affect parking, multiple use zones, bicycle and walking paths, etc.
Financial Incentives:	Tax incentives to encourage development patterns
Taxes and Fees:	Penalties and surcharges for development in conflict with planned land use.
Direct Govt Action:	Comprehensive land use planning paradigm to encourage high density, multi-use areas, reurbanization, residential intensification, etc.

Residential

(i) User Education/Practices

Information:	Broad-based campaign highlighting housekeeping measures and the environmental impact of energy use and conservation; tax credits for energy audits
Financial Incentives:	Tax incentives, low cost loans and direct subsidies for energy conservation projects and home improvements
Taxes and Fees:	see Section 10.2.1
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	In-house "action"'campaigns with energy use reduction targets

(ii) Passive Solar Heating

RD&D:	Continued research on and demonstration of passive solar (major improvements to windows, thermal storage, day-lighting in commercial buildings); research on and demonstration of solar

	water heating (cost, mechanical reliability, solar efficiency and storage).
Information:	Labelling, warranties, audit recommendations, information/advertising campaign for architects, builders, developers, homeowners
Regulation:	Specification in building codes
Financial Incentives:	Tax incentives, direct payments (akin to the concept of Demand Side Management), low cost loans to defray up-front capital costs.
Taxes and Fees:	see Section 10.2.1
Marketable Permits:	see Section 10.2.1
Direct Govt Action:	Government installations as demonstration projects

APPENDIX F

LIST OF CONTACTS

Appendix F

List of Contacts

I. Adam	City of Vancouver
S. Bolcso	Energy, Mines and Resources (Office of Energy Research and Development)
N. Brett-Davies	MacMillan Bloedel (Corporate Forestry)
R. Brown	B.C. Ministry of Forests (Silviculture Branch)
T. Cave	B.C. Hydro
P. Cochrane	B.C. Hydro
R. Clevette	B.C. Ministry of Forests
J. Gibbon	B.C. Hydro (Resource Management)
R. Kadulski	Solar Energy Society of Canada
H. Kimmins	University of British Columbia, Faculty of Forestry
A. MacCaffey	City of Vancouver (Policy)
B. McCloy	Council of Forest Industries (Environment)
B. MacDonald	City of Vancouver (Parking Branch)
H. Mohammed	Energy, Mines and Resources (Office of Energy Research and Development)
J.E.Persson	H.A. Simons (International) Ltd.
P. Sagert	Cirrus Consultants
B. Smith	Agricultural Land Commission
D. Spittlehouse	B.C. Ministry of Forests (Forest Climatology-Hydrology Research Branch)
B. Stipdonk	B.C. Ministry of Energy, Mines and Petroleum Resources (Energy Management Branch)
L. Vancea	Energy, Mines and Resources Canada (Office of Energy Research and Development)
K.C. Van Kooten	University of British Columbia (Forest Economics and Policy Analysis)
M. Wellisch	MacMillan Bloedel (environmental engineer)

GLOSSARY

GLOSSARY

a	Acre (=.405 hectares)
AAC	Annual Allowable Cut
ADMT	Air-dried metric tonne
AVR	Average Vehicle Ridership
BCH	B.C. Hydro Corporation
BOD	Biochemical oxygen demand
Btu	British thermal unit (measure of energy)
C	Carbon
CAFE	Corporate average fuel efficiency
CIPEC	Canadian Industry Program for Energy Conservation
CNG	Compressed natural gas (transportation fuel)
CO	Carbon monoxide
CO2	Carbon dioxide
COFI	Council of Forest Industries
CPPA	Canadian Pulp and Paper Association
CTMP	Chemo-thermal mechanical pulping
DFO	Diesel fuel oil
ECO	Energy Conservation Opportunity
EMPR	B.C. Ministry of Energy, Mines and Petroleum Resources
EMR	Energy, Mines and Resources Canada
ETC	Employee Transportation Coordinator
GHG	Greenhouse gases
ha	Hectare
HC	Hydrocarbons
HFO	Heavy fuel oil
IPP	Independent Power Producer
I/M	Inspection and maintenance program
kADMT	Thousands air-dry metric tonnes
kt	Thousands of tonnes
LFO	Light fuel oil
LPG	Liquid petroleum gases
MEE	Multiple effect evaporation

MUD	Multiple unit dwelling
NSPs	New Source Performance Standard
NSR	Not sufficiently stocked (forest lands)
Paprican	Pulp and Paper Research Institute of Canada
RD&D	Research, development and demonstration
SCAQMD	South Coast Air Quality Management District (California)
SFD	Single family dwelling
t	Metric tonne
T	Tons (=.907 tonnes)
TMP	Thermo-mechanical pulping
TSS	Total suspended solids (solid material in effluent)
VMT	Vehicle miles travelled
VRE	Vapour recompression evaporation
ZEV	Zero emission vehicles

International System of Units (SI): Prefixes

Prefix	SI Symbol	Multiplication Factor
exa	E	10^{18} (1,000,000,000,000,000,000)
peta	P	10^{15} (1,000,000,000,000,000)
tera	T	10^{12} (1,000,000,000,000)
giga	G	10^{9} (1,000,000,000)
mega	M	10^{6} (1,000,000)
kilo	k	10^{3} (1,000)
hecto	h	10^{2} (100)
deca	da	10

Examples: 1 Teragram or Tg (10^{12} or 1,000,000,000,000 or 1 trillion grams); 1 megawatt-electric or MWe (10^{6} or 1,000,000 or 1 million watts-electric.)

Exception: 10^{15} (1,000,000,000,000,000) British thermal units (Btu) is not generally referred to as a PBtu. Instead it is known as a quad, or one quadrillion Btu's.

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